The WELDING JOURNAL

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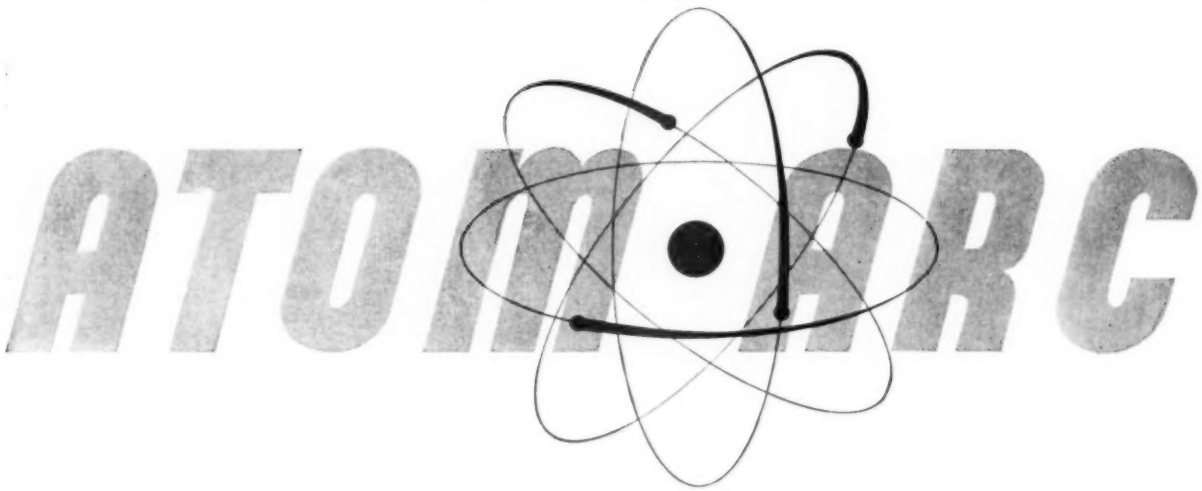

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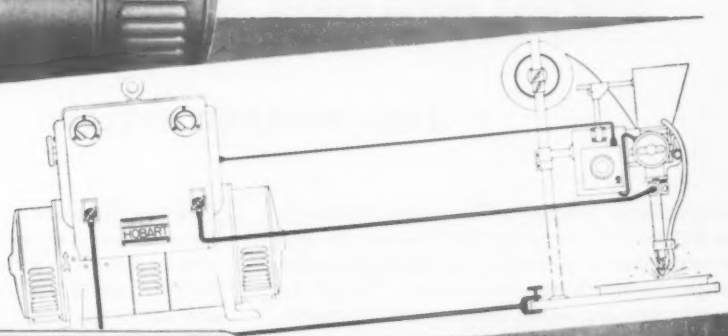

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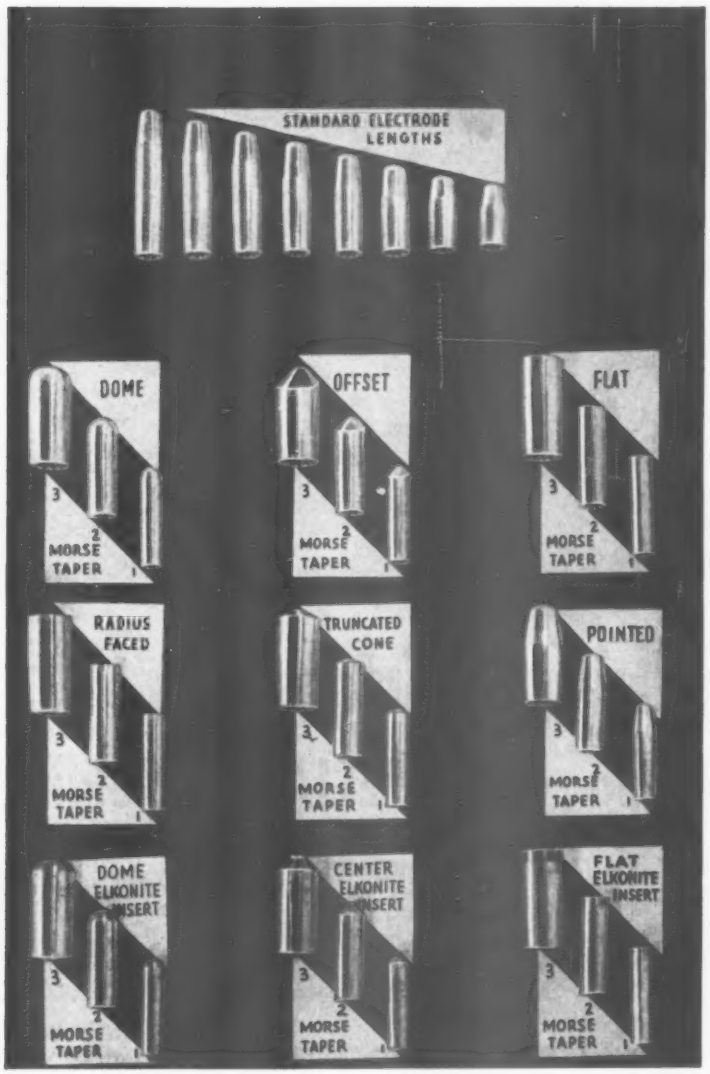

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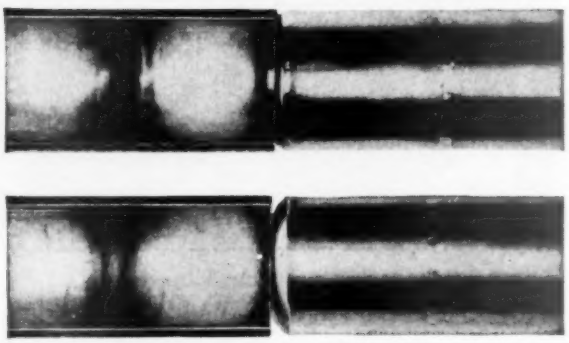

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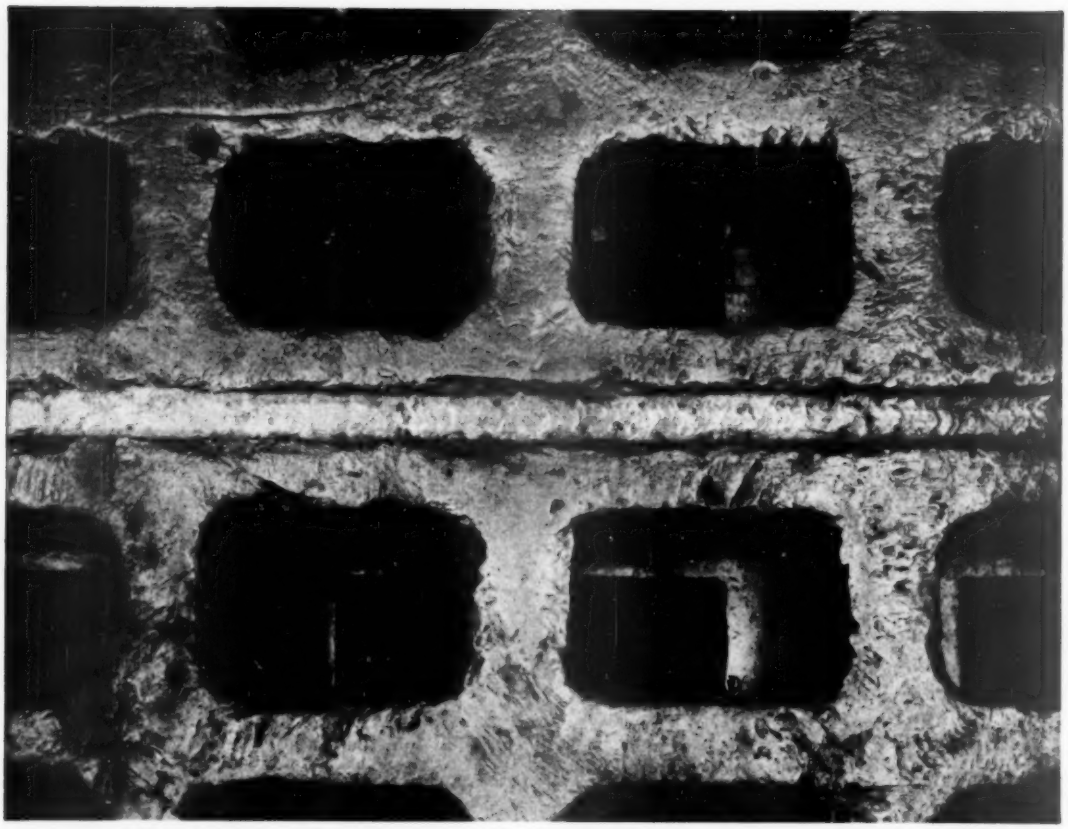

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The WELDING JOURNAL

volume 33 October 1954 number 10

Flash Welding High Strength Alloy Steels

Current practice in flash welding high-strength low alloy tubing used in aircraft landing gear

by W. G. Fassnacht

FLASH welding has received considerable scientific treatment at the last several Annual Meetings in the form of reports by Dr. Savage and his associates at Rensselaer Polytechnic Institute. When these studies are complete, one may be able to set up on any welder the best possible conditions for a job without going through the trial and error tests now required. Industry would certainly welcome such a situation, but unfortunately, they were unable to wait until Utopia arrived before making flash welds. In the following report are described the practices currently being used with a considerable degree of success in one factory that manufactures aircraft landing gear. The welds, from about 1 to 20 sq in. in area, are made in tubular sections of low alloy, high-strength steels, such as AMS 6324, 6415 and 6427, which are subsequently heat treated to tensile strengths of 180,000 psi up to as high as 240,000.

A brief review of the method of operation of a flash welder seems to be in order. It is a butt welding process in which the two parts to be joined are gripped by two current-carrying members, one of which is able to be moved toward the other under controlled conditions. It is moved continuously at a slow but increasing rate for the flashing portion of the cycle. The flashing occurs because the parts touch only in small, localized areas which carry a very high current density. These areas are almost immediately melted, and as the current continues to flow, the molten metal in the pools is violently erupted due to magnetic or other electrical forces,

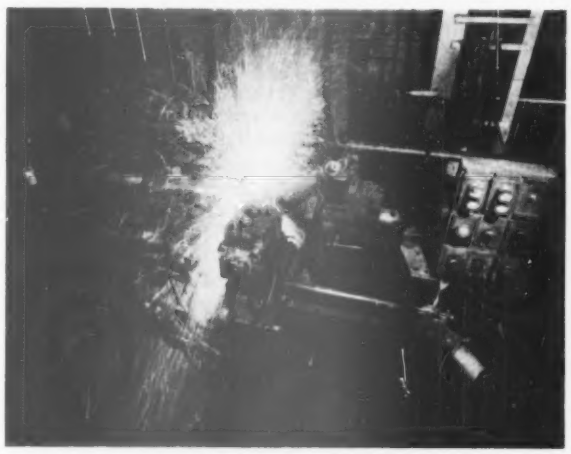

Fig. 1 A flash welder in operation

and/or possibly vapor pressure of superheated iron, into a veritable shower of sparks called "flash," Fig. 1. Not all of the heated metal is blown-out, and as the flashing continues the ends of the sections are heated to a high enough temperature to be weldable, at which time the parts are rapidly squeezed together and the current turned off.

In a modern flash welder, there are several conditions that can be varied in order to produce the quality of weld that is desired. Table 1 lists a number of these, and a quick glance will tell you that to set up a test program to find the optimum setting for each variable on a large number of sizes of material would be a task of considerable magnitude.

But why is it necessary to have such a large number of variables? Making a quality weld, which, incidentally, is more difficult for the alloys mentioned above than for plain carbon steels, is dependent upon maintaining the flashing (or heating) and the upset (or welding) portions

W. G. Fassnacht is Assistant Chief Metallurgist, Bendix Products Division, Bendix Aviation Corp., South Bend, Ind.

Scheduled for presentation at the Thirty-Fifth AWS National Fall Meeting to be held in Chicago, Ill., Nov. 1–5, 1954.

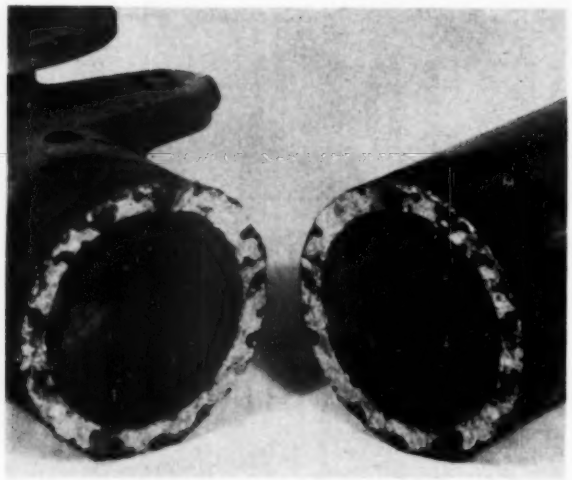

Fig. 2 A weld halted during the flashing phase by "freezing." Note holes (dark areas) where metal had been expelled. Deep holes are believed to be the source of penetrators

of the cycle between certain limits. If these limits are exceeded, weld strength suffers, if indeed the weld can even be completed.

DEFECTS DESCRIBED

The correct upset is usually determined by the amount of material squeezed together (sometimes called gather), although in some critical jobs, the speed and the current characteristics during upset also must be considered. In this author's opinion, however, the flashing cycle is much, much more critical. The limits between which this phase must be maintained are "freezing" (under-heating) and the production of detrimental "Penetrators" (overheating).

Freezing is a condition in the flashing cycle wherein too much of the cross-sectional area is in contact at one time. This causes the current density in the local shorts to become so low that the explosive forces mentioned above are too small to blow out the molten pools. When this happens, flashing is arrested. Figure 2 shows a joint that froze and was broken apart. The light areas were those in contact, while the dark ones are holes that were left in the opposing faces by a metal expulsion at some time prior to the freeze. It is easy to correct this condition by raising the voltage or decreasing the speed, although if freezing occurs on a cycle that has previously given satisfactory results, other factors should be investigated, cleanliness of electrodes and piece parts being a major one. Correction by raising voltage is not to be done too hastily, because the higher energy input that accompanies this might be conducive to the opposite trouble, that is, the production of penetrators.

Penetrators are weak areas found in completed welds, and are sometimes called "flat spots." They may be very small or large enough to cover a considerable portion of a weld, and can be recognized in a fractured piece as flat areas of markedly different color tone than the

Fig. 3 Weld containing serious penetrators. Dark spots are quench cracks which often occur in the weak areas formed where the penetrators are fairly extensive. Penetrators break with a flat fracture

balance of the fracture, even if it, too, is in the weld. Figure 3 shows a fracture containing serious penetrators, sufficient to cause cracks to develop in the weld plane over a portion of the defective area. Figure 4 shows the smaller type, produced by the same phenomena as the large ones, but which, because of their small size, are not detrimental to the static strength of the weld, although they will force a break into the weld line and decrease the ductility.

Fig. 4 Small penetrators occurring in tensile test bars. These small areas cause little, if any, decrease in tensile strength, but do trigger the fracture and reduce elongation

What causes penetrators? Undoubtedly, their formation is intimately tied up with the area and depth of the blow-outs formed during flashing. You will note the dark areas on the fracture shown in Fig. 2 are quite shallow, as would be expected on a piece that froze, the product of a low energy input. Deeper depressions, which are formed with higher voltages, have a relatively high temperature gradient from top to bottom because, in flash welding, the temperatures vary from at or near melting where the flashing is occurring to room temperature at the electrodes, a distance often of less than 1 inch. If a deep hole were blown out shortly before the upset started, one or more of the following conditions would be extant during the upset:

1. As the parts are being forced together, the bottom of the hole, which is the coolest, would contact last and therefore be subjected to less pressure than the hotter, more weldable edges. Therefore, the weld at what was the bottom of the hole would be weaker than the surrounding area.

2. There may be some gas trapped between the approaching walls of the holes. The gas will be subjected to high pressures which, at the high temperatures existing, would cause some to be dissolved. On cooling, the gas would tend to come out of solution, thus forming an internal pressure which would weaken the weld, following in pattern the flakes that are formed in certain forging steels.

3. If one of the contacting gases is oxygen, some oxides might be formed. Due to the lower pressures where the bottom of the hole was, and to the lack of fluidity of the oxides, these might not be expelled. This would form a non-metallic inclusion in the weld line.

Any of these conditions, alone or in combination, could, in this writer's opinion, cause a penetrator. An important method of minimizing penetrators is to use a voltage that is as low as is possible to consistently maintain flashing.

It is probably impossible to make welds in commercial quantities that are completely free from all penetrators, but with proper control of the weld cycle, these defects can be reduced to a point where they do not adversely affect weld strength, even in parts subsequently heat treated to tensile strengths in excess of 200,000 psi. A freeze makes itself evident as soon as it occurs, but penetrators, even those sufficient to damage a weld, will not show up until subsequent inspection or, since there is at this time no non-destructive test that will find all flat spots, maybe not until after the joint is in service. For these reasons, the welding cycles must be selected carefully. Most of the variables listed in Table 1 must be changed every time the size of the pieces being welded is changed. Those which we normally alter from setup to setup are noted in the list by a "c." Therefore, any welder built for doing more than one job must have a suitable number of controls built in to permit the required cycle to be set up.

Table 1—List of Flashwelding Variables

Amount of manual burnoff (c)
Amount of automatic burnoff (c)
Time for automatic burnoff (c)
Platen motion curve
Distance between electrodes (c)
Amount of upset (c)
Speed of upset
Applied voltages (c)
Point of voltage change (c)
Current cut-off time after upset (c)
Volume of protective atmosphere (c)
Clamp contact area (c)
Clamping force
Flashing force
Upset force

(c) Variables that are normally changed whenever a different set up is made.

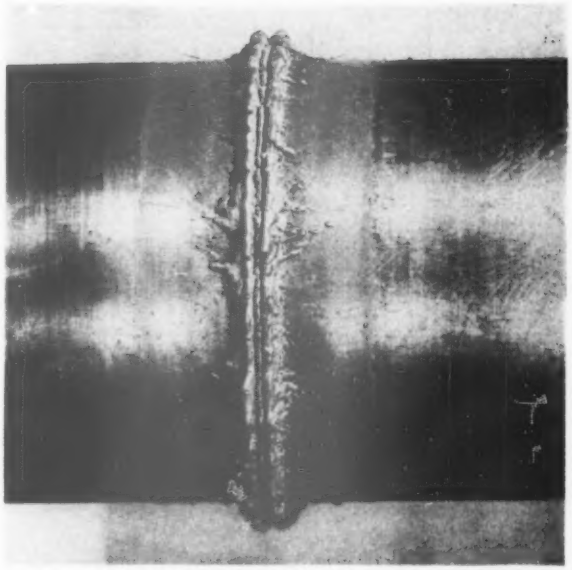

Fig. 5 External appearance of a satisfactory weld. Note the "tongue" appearing between the upset material

DETERMINING THE CYCLE

The importance of keeping the blow-outs shallow has been pointed out. How, then, do we go about establishing the values for all these variables in order to produce quality welds. As mentioned before, to vary all of these would create a prodigious testing program. But there are certain data available to shorten this procedure. If you are starting from scratch, you will find that tables of burn-off amounts and times, upset amounts, distances between electrodes, and electrode contact areas for many sizes of materials are published in the Resistance Welder Manufacturers' Association book, "Resistance Welding Manual," and in the AMERICAN WELDING SOCIETY'S "Welding Handbook." Or, it may be possible to obtain the data developed by one of the industrial users of flash welding. It is well to select at least 3 sizes of material bracketing the range you will be welding. Make setups using data you have chosen and change other variables especially voltage, until you find a combination that will just carry without freezing. When cycles for all three sizes are satisfactorily determined, curves can be plotted to guide you in welding other sizes.

A good weld will have the appearance of that shown on Fig. 5. The tongue exuded from the middle of the weld is a very good sign. While its presence does not guarantee a good weld, its absence is an indication of a poor one. The upset should form an angle of about 45–60° with the surface of the base metal. Using less upset increases the possibility that some of the flashing holes will not be closed up, while excessive gather forces the hotter, more weldable metal into the upset so that the actual weld is made in "cold" material. This reduces weld strength and ductility.

As a result of this type of test program, we have de-

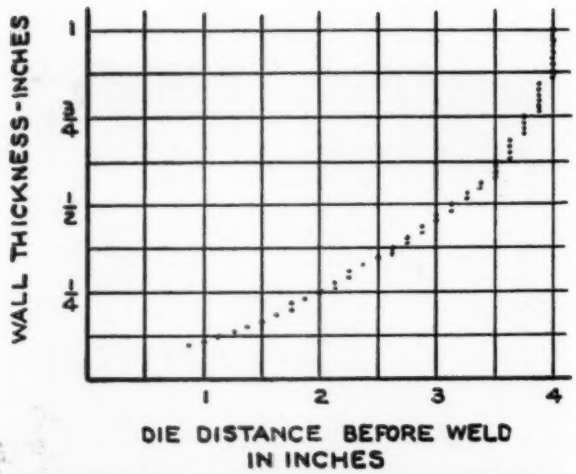

Fig. 6 Chart showing relationship between wall thickness and the distance between electrodes before weld

veloped a series of graphs and tables from which we obtain the cycles for our welders. We are currently operating a 600 kva Swift Welder, which has been in use since 1942, and a 1200 kva Taylor-Winfield which was started up in the summer of 1953. Due to the inherent differences in the construction of the two machines, there is not much in the way of intrinsic values that can be transferred from one to the other. As a matter-of-fact, the only two items that are used identically on both machines are the die distance before weld and the total loss.

SET-UP CHARTS EXPLAINED

Figure 6 is a chart of the die distances, that is, the space between the electrodes before the weld is started. The distance used is dependent upon wall thickness, although it is not a straight line function. It is not a critical dimension, plus or minus $^1/_{16}$ in. apparently not having any effect on the welding cycle, but since that tolerance is easy to maintain, it should be held in order to reduce the discrepancies from setup to setup to an absolute minimum.

Figure 7 is a graph showing the total loss and the burn-off. This latter phase of the cycle could also have been made the same for the 1200 kva welder as that used for the 600, but it is our intention to use the former for some joints appreciably smaller than are customarily welded on a machine with such great capacity. Consequently, we increased the speed a little over what would be used for similar sizes on the other machine. The ensuing decrease in time lowered the amount of heat run back into the ends of the parts, so that it took a little less upset to give the desired 45–60° upset angle. In order to maintain the total loss, it was therefore necessary to add a little to the burn-off on the 1200 kva. Our tests have indicated no loss in weld quality, which is not surprising, since, at the present time, success in flash welding depends upon achieving a proper balance among the different variables, and this can be done in numerous ways.

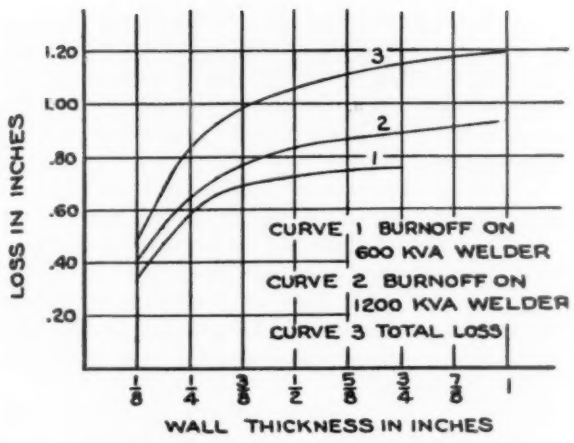

Fig. 7 Graph of the amounts of burn-off and total loss and their variation with wall thickness

It might be noted here that the difference between the burn-off curve and that showing the total loss is *not* the amount of upset either as noted on a dry run, (a run-through of the cycle without benefit of parts or welding current) or according to any calibrated devices on the welder. The total loss curve is computed for measurements on the welded part after it has cooled to room temperature while the upset is done with the metal at quite high temperatures. The machine settings must therefore be chosen to compensate for shrinkage during cooling and also for any deflections that might occur in the machine when the upset pressures are applied.

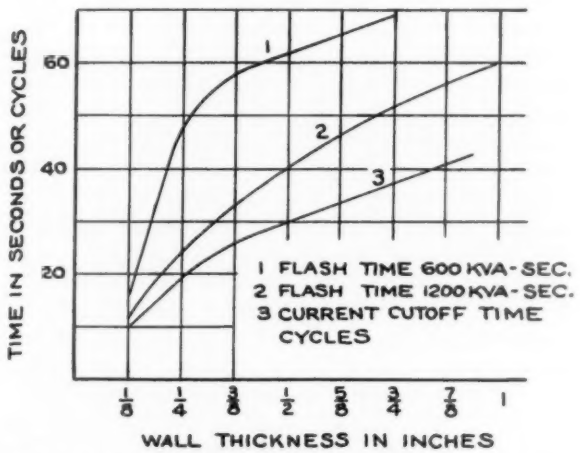

Fig. 8 Time relationships used in flashwelding. Curves 1 and 2 are for flashing, curve 3 for carrying the current into the upset

Burn-off and total loss, like die distance, are variable with wall thickness. So is time. Figure 8 shows the values established for this. There actually is less difference between the two machines than the flashing curves indicate since the 600 kva values are for the entire flashing cycle, while the others are only for the automatic portion. An addition of from two to about twenty seconds, depending partly upon wall thickness

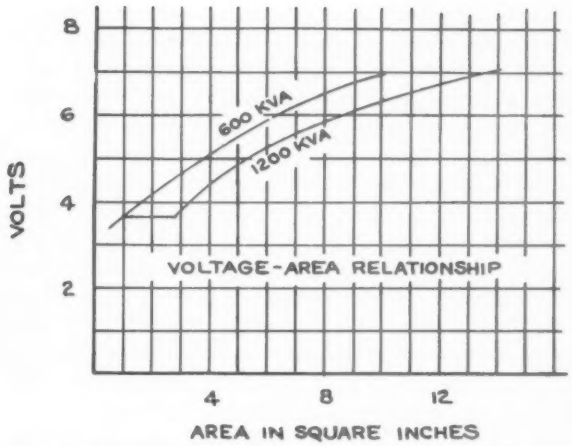

Fig. 9 Voltages used for welding. Note that this is based on cross-sectional area while the other phases of the cycle are based on wall thickness

and partly upon the operator, must be made to the 1200 kva times to have really comparable figures. The third curve appearing on this graph shows the length of time that the current is kept on after the upset is initiated. It is not felt that this value is too critical except for the following conditions: (1) the current must not be turned off before the upset starts, and (2) in the case of thinner walled tubes, the high amperage caused by the dead short during upset could cause overheating of the metal, especially in the area at the base of the upset, if left on too long. But, as in the case of die distance, in order to keep the variables under the best possible control, current cut-off is set according to this curve.

A third graph, shown in Fig. 9, was prepared as a guide for new setups. This one indicates the voltages found by trial and test to give satisfactory results on a number of different tube sizes. When plotted, the curve gives a fairly accurate indication of the voltage required for any new job, although slight adjustments may be necessary. It cannot be too strongly emphasized that these values are set as low as will consistently maintain flashing when die distance, burn-off and time have been set up according to the previously mentioned data sheets. The variation between the machines, as shown on this graph, is due partly to inherent differences in construction and partly to the conditions under which the meters are read. Unless these factors are identical, tranferring voltages from one machine to another is impractical.

REPEATABILITY IS A MUST

Once a good cycle is established, it is necessary to be able to set it up again and again, especially if several jobs are being run on one machine. This requires adequate instrumentation. Pressure gages, voltmeters, etc., are usually supplied with welders and are necessary adjuncts to satisfactory operation of the machine, but there is one gage not normally furnished that this author would not do without. This is an

Fig. 10 Control panel of a welder, showing a dial indicator in place for measuring platen travel

ordinary dial indicator of sufficient stroke to allow observation of the entire platen movement during both flashing and upset. This means that it must be mounted between the movable platen and the frame. Figure 10 shows such a gage in place on the 1200 kva machine. To use it, two pieces to be welded are placed in the machine and the zero point is set where the ends of the piece part just touch, that is, where flashing would just commence. After the zero point is determined, one part is removed. The machine can then be put through a "dry run" and the controls adjusted until the various phases of the cycle occur exactly where desired, usually within plus or minus 0.005 in. of the setting aimed for. Such accurate control of the setup is necessary to maintain close length tolerances as well as to insure adequate weld quality. While most welders are furnished with calibrations of one sort or another for making a setup, it has been found that these are generally not accurate enough to give the degree of repetition required for high strength welds, and the simplest way to know that the phase changes occur when wanted is to use an indicator as described above. Sometimes it is advantageous to use the indicator during an actual weld. In this case, it must be electrically insulated, because the mounting is usually such that there is a voltage between the indicator and the block that actuates the plunger. If any current passes through the instrument, it has a disconcerting way of melting the insides.

ATMOSPHERE CAN IMPROVE A WELD

Another factor to be considered in the production of quality welds is the use of a protective atmosphere. Two types can be used, inert or reducing. The former, such as helium or argon, performs one function only—to exclude air from the hot surfaces in order that oxides will not be formed. The latter does this, too, but it also seems to contribute a further benefit. If a flashing cycle is started without reducing atmosphere and the gas is then turned on, a noticeable quieting of the arcing will take place. The result of this is to decrease the size of the holes blown in the ends of the parts. As was mentioned before, this is a desirable condition in producing a high-strength weld. This author is not aware of any experiments made to determine just which reducing gas is the best. A satisfactory atmosphere is a 1000 Btu mixed gas, consisting essentially of CH_4, CO, H_2, and a few higher hydrocarbons. Coal gas and acetylene have also been used successfully. Tests run at Battelle Memorial Institute have shown similar properties for hydrogen alone. One bad feature of carbonaceous bases is that the carbon content of the internal flash (those frozen globules of metal that are expelled into the inside of the tube) is materially raised, which makes the flash much more difficult to remove if it must be done by machining. It is to be noted that the government flashwelding specification, MIL-W-6873, requires the use of gas on tubular sections over 0.149 in. in wall thickness, although it indicates no preference between inert and reducing. With the 1000 Btu gas, it has been found that it requires about 10 cfh per inch of diameter to give satisfactory results. A significantly larger flow causes the faces of the flashing tubes to be chilled, since the gas is introduced into the bore of one piece part and made to flow out across the hot ends. A lower flow gives inadequate protection.

A LOOK AT TESTING METHODS

Until now, only the details of a satisfactory welding cycle have been considered, with no thought of the test work necessary to find out if we have one. Since, as noted before, there are no nondestructive tests that will pick out penetrators 100%, we are forced to use less than perfect methods. Submersed ultrasonics have shown considerable promise but this process is not in commercial use yet. X-ray is not good except for gross defects that can be picked up more economically by other methods. Magnetic particle inspection will show up many, but not all, penetrators. It is a valuable production inspection tool, but for starting out, no better way has been found than to make tests on sections of the welds. Microscopic examination has a place, but it is very expensive considering the small amount of area examined, and is not too effective in finding tight penetrators. So tensile testing has formed the bulk of the inspection of experimental pieces.

The samples used to set up cycles are pieces of tubing of the same alloy and cross-sectional dimensions as the parts they represent. They are five inches long, and, when welded, form a tube between $8\frac{1}{2}$ and $9\frac{1}{2}$ inches long, depending upon the loss in welding. Two or three different cycles are tried at first giving that number of welded tubes. After a suitable softening heat treatment, the OD and, wherever possible, the ID are machined to reduce the cross-sectional area for a couple inches across the weld. The part is then Magnafluxed, and if satisfactory, longitudinal cuts about 1 in. apart are made from the OD almost to the ID. This leaves the tube so that it can be heat treated in one piece and then easily separated into suitable test bars. The tube is heat treated to a hardness at least equal to, but usually higher than, that required on the part it represents. The bars are then broken apart and pulled. In this way, all of the weld is tested except that which has been removed by machining.

The most satisfactory piece, of course, is one that breaks in the base metal. But if a failure does occur in the weld, it is usually caused by a penetrator which is thus exposed and can be readily seen on the fractured surface. Any weld which has even one bar that pulls at less than 90% of the base metal strength is considered unsatisfactory.

QUALIFICATION PROCEDURE

If a satisfactory weld has been produced, three more welds are made using the same cycle. These are prepared and tested as above and must be found satisfactory before production can be started. With sufficient experience, the three-weld series can be made with no preliminaries. If military certification is required, up to 15 samples are required.

Steels have been divided into 6 classes for purposes of cycle qualification. The first five are plain or low alloy steels of increasing hardenability, while the last stainless. A cycle qualified on any one of the five is considered satisfactory for all lower classes, but if a job is received for a higher class, requalification must be made. Requalification is also required within a class if the new job is heat treated to a higher hardness than were the original test bars or if the size varies by more than $\frac{1}{32}$ in. for outside diameter or $\frac{1}{64}$ in. for wall thickness. For stainless, only the 18–8 type has been considered so far. Welding conditions are so much different for this alloy than for Class 5 or lower, that no cycle can be considered satisfactory for both.

When qualification has been completed and a production run is ready, the data for machine settings is furnished to the welding department by the metallurgical laboratory, which had been in charge of the setup and test work that preceded production. This information is contained in a data sheet, one of which is delivered to the welder for each and every setup. In the course of a run, every weld is assigned a serial number which is stamped on the assembly and remains even on the finished part. These serial numbers are listed on

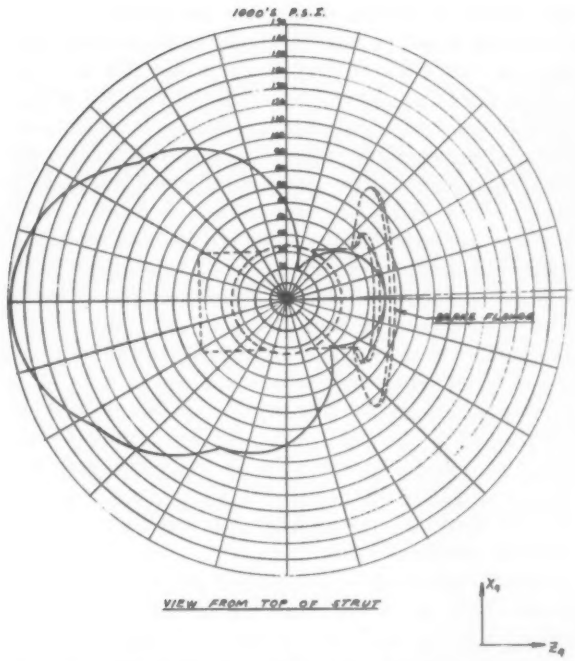

Fig. 11 A polar diagram of the distribution of maximum tensile stress around a landing gear inner cylinder. Used for magnetic indication acceptability, it shows where the size of the indications must be kept to a minimum in order to provide adequate repeated load life

auxiliary sheets which are attached to the original data sheet. All inspection tests made by the welding department, or any irregularities of machine performance, are noted against the appropriate number. After subsequent inspections, all weld defects, whether rejectable or not, are charged against the serial number in order to correlate machine operation with weld quality.

PRODUCTION TESTING FOLLOWS DIFFERENT LINES

For production pieces, inspection must follow a nondestructive course. Two methods are used, proof testing and Magnaflux. The former is required by MIL-W-6873, unless periodic samples, either special coupons or actual piece parts, are tested to destruction. Since breaking tests are impractical for the large sizes being considered, proof testing is performed on 100% of the welds. This is done by stressing the parts the same way that they are in service, that is, tension or bending. The loads used are based on the design yield point of the finished product. If a bend test is used, the load is put on in four directions at right angles to each other.

Magnetic inspection is done at least three times (1) after heat treatment and removal of the external upset (2) after proof testing but before any plating operations and (3) just before assembly. While most pieces are completely free of all indications, there are some that have tiny ones, while occasionally a longer one appears. Repeated load tests have proved that very short indications are inconsequential at the number of cycles experienced by landing gear. By this token, most of the welds having magnetic indications can be accepted. But to further evaluate the effect of these penetrators, a polar diagram is drawn of each part subject to bending loads. These show the maximum tensile stress that will be incurred in service at any position around the weld. Figure 11 is an example. Acceptance is based on the size of the indication and its relationship to the load shown on the diagram. This procedure has allowed well over 90% of all Magnaflux indications found to be accepted without jeopardizing performance of the parts in the field. Generally speaking, an indication over $^3/_{32}$ in. long is believed to be detrimental, and any weld found containing one this long is rejected regardless of its position in the polar diagram.

WELDER TOOLING IS IMPORTANT, TOO

Weld quality does not consist of strength alone. Ability to hold dimensional tolerances is also an important factor. These include length, shift, twist and bow.

Modern machines, using stop nuts to limit platen travel, have no trouble maintaining length tolerances of plus or minus $^1/_{32}$ in. With adequate control of time and energy input, the heat imparted to the parts is uniform. This gives an equally uniform shrinkage in cooling. However, there must also be a uniform placement of the parts in the machine and no slipping in the electrodes during upset. Therefore, adequate backup tooling must be used. These tools are also the means of maintaining the other tolerances, especially shift and twist. Bow, which is the amount that the centerlines of the components of an assembly are out of a straight line, is often remediable after the weld has been completed, but it is still best to hold it as close as possible in the welder. Tolerances are ordinarily set at 0.030 in. total indicator reading when swung on the centers of the original parts. Shift and twist, once put into an assembly, are there to stay, and only the presence of sufficient machining stock can overcome them.

Shift, which is the amount by which the original centerlines fail to meet, is generally produced when the areas that transmit the upset pressure to the backstops are not on, or at least near, the axes of the parts being welded. An off-center pressure pad or locating point can be counter-balanced by another on the other side, or even one right on the axis. But extreme care must be taken when such an arrangement is used because, despite location tolerances put on prints, the pads are often machined so that only one takes pressure until something slips and the other can pick up its share of the load. Result—shift. If two pressure points must be used, the situation can be remedied by making one pad on the tool fixed and the other movable so that it can be adjusted for every piece, thus nullifying the discrepancies.

Control of twist involves locating on the critical areas and providing the means of putting the locators in the proper radial alignment. A good way to accomplish this is to provide box fixtures solidly fastened to the platens. By means of locating pins and bushings in these and the actual backstops, little difficulty is encountered in keeping twist to a minimum. Fortunately, many jobs need no control of this item.

The author has tried a number of methods to get the electrodes and backstops lined up properly before a weld is made. So far, nothing has been found that is better than putting a pair of the component parts in the machine exactly as they would be if a weld were to be made and setting them against the backstops by putting pressure on the ends. They are then moved apart until there is a gap of a few thousandths of an inch. This gap is then checked with a feeler gage to see if it is uniform around the entire circumference. If not, the electrodes and/or the backstops are adjusted until it is. Even this does not guarantee a straight, unshifted part. Only by making a weld and then adjusting to compensate for any movement due to the dynamic portion of the welding cycle can the ultimate be achieved.

HELPING OUT POSTWELD OPERATIONS

Where smooth bores are required or loose flash is likely to be detrimental, the internal flash and upset must be removed. This can be a very nasty machining operation, especially when the weld is quite a distance from an open end, if the bore is not large enough to permit a rigid boring bar to be used, or if there is a land between the weld and the open end. Unfortunately, various combinations of these circumstances often occur in landing gear. Not much can be done to prevent a rather heavy deposit of flash along the edges of the weld. The deposit in the ID is even heavier than that shown on the OD in Fig. 5. When this flash must be removed by machining, it is put in as machinable a condition as possible (and this still leaves much to be desired) by giving the parts a sub-critical anneal. Any extra softening gained by a full anneal or a normalize and temper is not particularly advantageous because the interrupted cuts and particles that break off are more destructive to the tool than the intrinsic hardness of the material being cut, although the combination of these with hard material can break tools almost faster than they can be installed.

In some cases, this heavy deposit can be removed by hot broaching. In several plants, this is done by an attachment that pushes or pulls the broach through the tube immediately after the upset is completed. It can even be done on a separate press providing unloading from the welder is quick enough.

Considerable flash is also sprayed around the interior of the tubes for several inches from the weld. This will stick to the walls unless they are treated with an anti-splatter compound. The best type seems to be a fire clay base. The lacquer types are not able to cope with the large amounts of splatter that are formed in this method of welding, while a silicone type left a nonadhering but very thin, continuous coat of flash that was quite difficult to remove.

While this paper is not intended to cover all aspects of flash welding, an attempt has been made to include most of the more important problems encountered. It is sincerely hoped that the data and suggestions contained herein will be of value to those who have problems in this type of joining.

Austenitic Manganese Steel Welding Electrodes

Discussion by J. A. Trainor and Robert Bramley

ABSTRACT OF WRITTEN DISCUSSION

J. A. Trainor called attention to a patent not covered in the paper (U. S. 1,732,202), and questioned the extent of cross licensing implied in the discussion of patents. He stated that the use of a single specification on occasion was the result of economic necessity rather than cross licensing.

J. A. Trainor, Taylor-Wharton Iron and Steel Co., High Bridge, N. J., and **Robert Bramley,** Sales Manager, Stulz-Sickles Co., 134–142 Lafayette St., Newark 5, N. J.

Paper by Howard S. Avery and Henry J. Chapin was published in the May 1954 issue of The Welding Journal, pp. 459–479.

Robert Bramley also mentioned the above patent and stated that U. S. Patent No. 1,876,738 had not been cross licensed.

Authors' Reply

There are a multitude of manganese steel patents that do not cover or mention welding rods and no attempt to cover these in the paper was made. U. S. Patents 577,851, issued to Robert Hadfield in 1897, and 1,732,202, issued to Hall and Comerford in 1929, refer to austenitic nickel-manganese steels and would be pertinent to a more extended historical survey.

Records available to the authors indicate that U. S. Patents 1,815,464 and 1,732,202 and Canadian Patents 302,154 and 307,129 were cross licensed. U. S. Patent 1,876,738 was not included, confirming Mr. Bramley's statement, and we thank him for the correction. Mr. Trainor's explanation of the use of the same specification by several companies seems reasonable, and is accepted as probably more valid than cross licensing.

Prediction of Angular Distortion Caused by One-Pass Fillet Welding

Data on measurements of the magnitude of free angular distortion caused by one-pass fillet welding in tee joints

by T. Kumose, T. Yoshida, T. Abbe and H. Onoue

Abstract

It would be convenient to know prior to undertaking the welding of a structure the magnitude of the potential angular distortion caused by horizontal fillet welds.

This research shows experimental values of angular distortion caused by one-pass fillet welding. Material used were all shipbuilding stock of mild steel plating thickness ranging between 6 and 16 mm, and welded under various conditions using leg length between 6 and 10 mm. Testpieces totaled three hundred. The magnitude of free angular distortion caused by one-pass fillet welding was measured and maximum value of angular distortion was found when flange thickness ranged between 10 and 12 mm in a tee joint.

Findings of effects of plastic and elastic prestrain upon angular distortion with the view of avoiding angular distortion are discussed, and, further, formulas and curves are given for immediate application of elastic prestrain to predetermine angular distortion in production welding.

1. FOREWORD

HORIZONTAL fillet welding is extensively used in shipbuilding practice. Better efficiency of horizontal fillet welding would immediately effect the whole welding process. This fact interested many shipyard welding engineers and modern technique introduced deep fillet welding or one-pass fillet welding.*

Distortion difficulties caused by butt welding are comparatively easier to handle. Avoidance of angular distortion caused by fillet welding, has not been considered much till recently. Some of the reasons of this trend could be attributed to the fact that publications on angular distortion caused by fillet welding could not be readily applied to practice, since each research was done under different conditions of multipass fillet welding and data on the subject were practically impossible to compile due to lack of unification of information. In the application of one-pass fillet welding in shipbuilding, welding conditions are different from that of multipass fillet. In contact welding (one-pass), analysis was made easier and compiled data was made useful for practice.

From the viewpoint of ship welding application, the co-authors, through this research, obtained material to predict quantities of free angular distortion caused by one-pass fillet welding done with a-c arc welders under conditions most applicable to shipyard practice (plate thickness and leg length), and further, material was sought to determine quantities of plastic prestrain and elastic prestrain in view of avoiding such distortion.

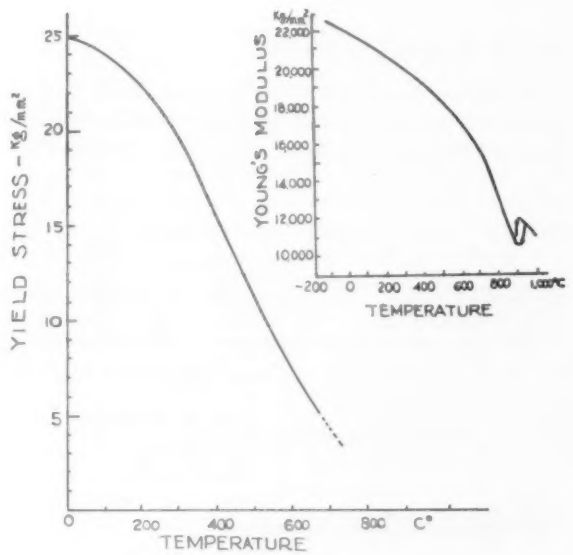

Fig. 1a Curve of temperature versus yield point of mild steels

Fig. 1b Curve of temperature versus Young's modulus of pure iron (from "Metal Handbook," p. 218, 1952, Japan Institute of Metals)

T. Kumose, Chief, Hull Section, Repair Department, **T. Yoshida**, Chief Riveting and Welding Shop, Shipbuilding Department, **T. Abbe** and **H. Onoue**, Welding Engineers, Welding Unit, Shipbuilding Department, Yokohama Shipyard and Engine Works, Mitsubishi Nippon Heavy Industries.

Paper scheduled for presentation at Thirty-Fifth AWS National Fall Meeting to be held in Chicago, Ill., Nov. 1–5, 1954.

* One-pass fillet welding meant here uses electrodes for horizontal fillet welding of large diameter and quick melting type for improved efficiency, and suitable for contact welding as well.

2. FREE ANGULAR DISTORTION

In general, yield stress and Young's modulus of mild steel tend to drop with increasing temperature as shown in Fig. 1*a* and 1*b*. When temperature of parent metal is in excess of 700° C (1292° F) while welding, the metal partially heated is constrained by regions of lower temperature or of larger rigidity and this causes plastic deformation at higher temperature zones. This deformation depends upon many factors, for instance, type of joint, leg length, plate thickness, temperature distribution and other metallurgical factors. This study, however, discusses data and results obtained from experiments done under various conditions, free from external forces, with factors that considerably effect angular distortion such as flange thickness of a tee joint, leg length and welding current.

2.1 *Method of Experiment*

An apparatus as shown in Fig. 2 was made and tee joints were welded. Dial indicators were used to take various readings of angular distortion. Angular distortion $S = \Delta\theta \cdot l$, where l is length of span and $\Delta\theta$ angle of distortion (see Fig. 3). (As mentioned in the following paragraphs, free angular distortion curves are shown in Fig. 4 and measuring vertical displacement S of flange instead of angles will give required distortion readings.) Materials used were all shipbuilding material SS41 rimmed steel plates (equivalent to Grade A steel as specified in the construction rules of the American Bureau of Shipping, section 39, paragraphs 10 & 11, 1953) and sizes of testpieces are shown in Fig. 3. Horizontal fillet welding was done by continuous progressive method with electrodes MS-152 (equivalent to E6020) diam 6 mm. All welds were done by a skilled test welding operator from the shipyard. Leg length, welding current, arc voltage and welding speed were all checked and adhered to during operation. Welded testpieces were all cooled down to room temperature prior to further welding on opposite sides of web and taking measurements for distortion. Positions of tack welds on testpieces as shown in Fig. 3 were all adhered to throughout the experiment. The number of testpieces totaled 159. Dial indicators were positioned at points A, B, C, A', B', C' and M as in Fig. 3, and angular distortion values taken in this study were mean values of vertical displacement read at both sides of flange, or mean values of angular distortion in way of lines AA', BB' and CC'.

Angular distortion in way of BB' line is:

$$S_{B-B'} = \frac{B + B' - 2M}{2}$$

where:

B, B' and M = dial indicator readings taken at B B' and M (see Fig. 2).

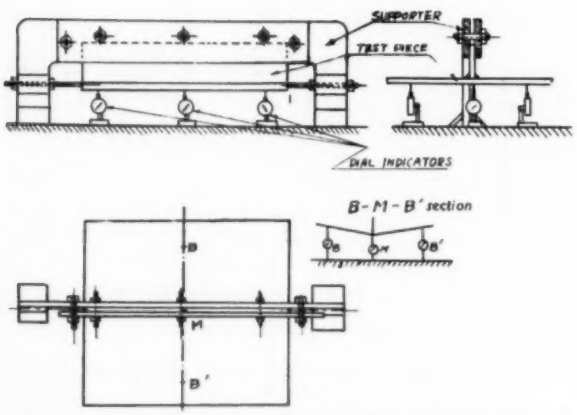

Fig. 2 Apparatus of measuring angular distortion caused by horizontal fillet welding

2.2 *Experimental Results*

(*a*) *Form of Angular Distortion.* Angular distortion curves for horizontal fillet welds of varying flange thickness are shown in Fig. 4, where leg length and current were kept constant, and operation free from external forces. Distortion analysis at immediate vicinity of beads, indicates that mean values of vertical displacement S on both sides of flanges are comparable with angular distortion.

(*b*) *Effect of Number of Passes.* It was found that one pass with an electrode of large diameter showed less distortion than multipass welding, see Fig. 5, where leg length and type of electrode were constant.

(*c*) *Effect of Root Gap.* Root gaps in excess of 1 mm affected angular distortion as shown in Fig. 6, where flange thickness 12 mm is horizontal fillet welded with

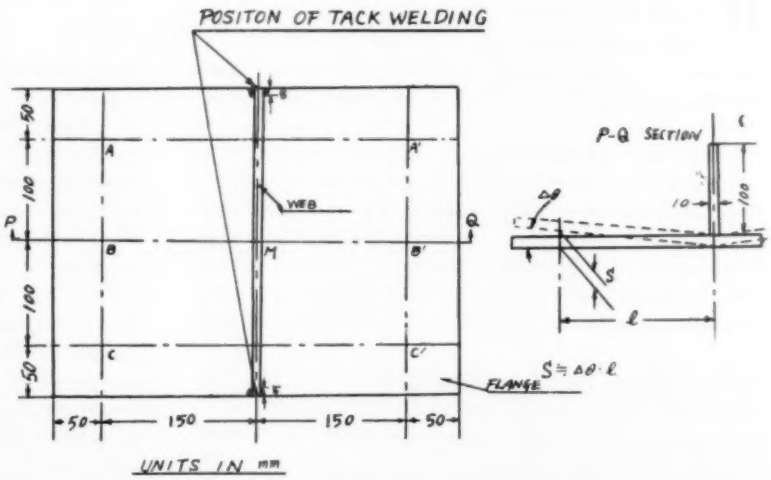

Fig. 3 Detail of testpiece dimensions

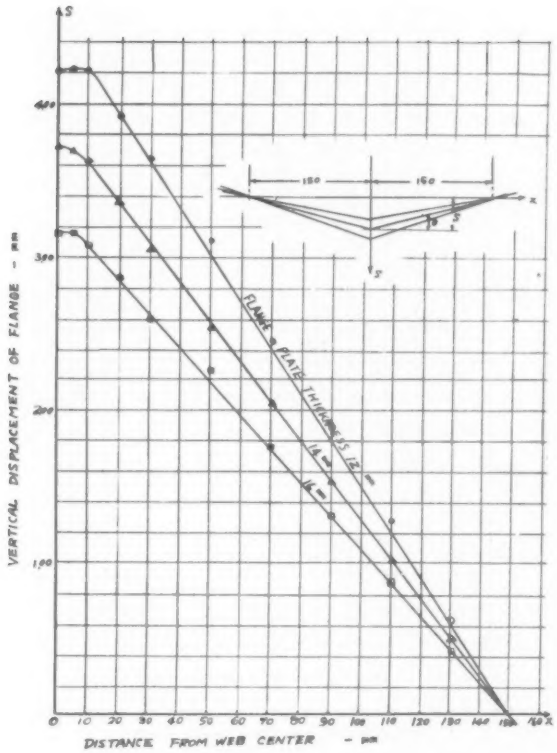

Fig. 4 Form of free angular distortion

varying root gaps, and leg length set at 7.5 mm throughout. In practice, larger leg lengths are required with increasing root gaps, and distortion increases accordingly as stated in the following paragraph.

(*d*) *Effect of Deposited Metal.* Greater deposited metal showed larger angular distortion. Logarithmic value of weight per linear length of deposited metal, log

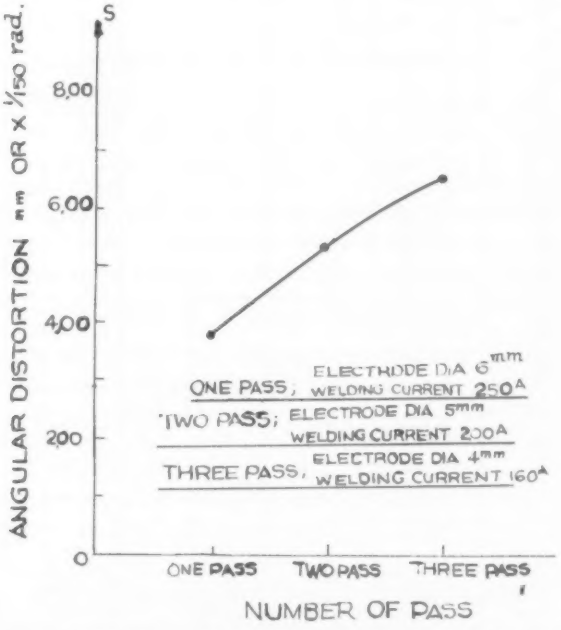

Fig. 5 Comparison of angular distortion caused by one pass and multipass welding

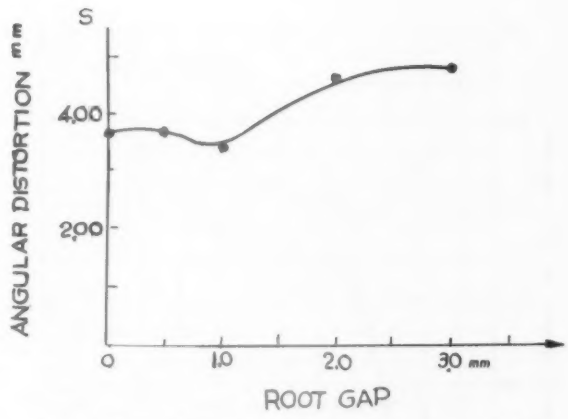

Fig. 6 Example of effects of root gap upon angular distortion

W, and angular distortion were found to be approximately in proportional relations, see Fig. 7.*

(*e*) *Effect of Flange Thickness of Tee Joint.* Relations between flange thickness and angular distortion are shown in Fig. 8 through 11 with varying leg lengths 6, 7.5, 9 and 10 mm, respectively. Maximum angular distortion ranged between flange thickness 10 and 12 mm, and peaks were on the thicker side with increasing welding currents.

(*f*) *Effect of Welding Speed* (*Effect of Current*). Increasing welding speed, in other words higher amperes since leg length was constant, showed increasing angular distortion on flange thicknesses in excess of 10 mm (see

* This agrees with experimental results introduced by Dr. H. Kihara and others, Welding Division, Engineering Research Laboratory, Ministry of Transportation, at the 1953 Winter Meeting of the Welding Committee, the Society of Naval Architects of Japan.

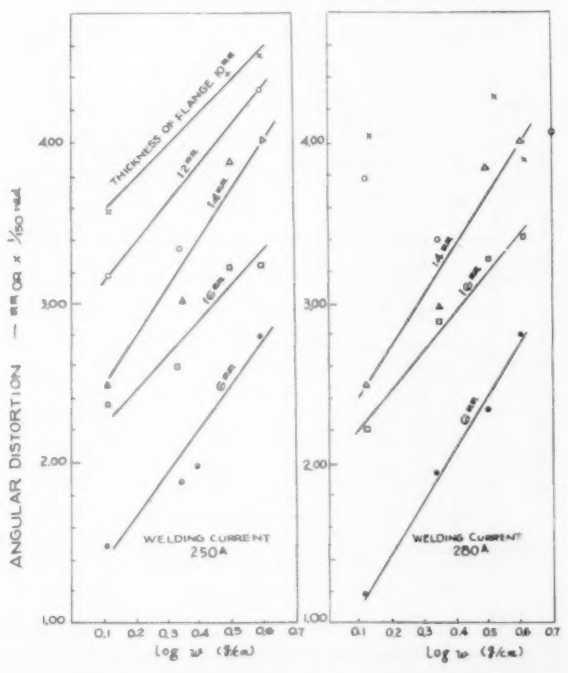

Fig. 7 Curves of angular distortion versus logarithmic value of weight per linear length of deposited metal

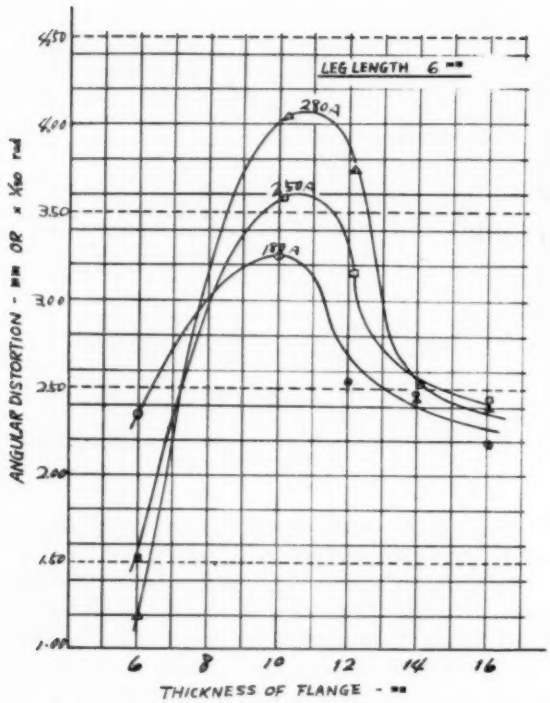

Fig. 8 Curves of angular distortion versus flange thickness, leg length 6 mm

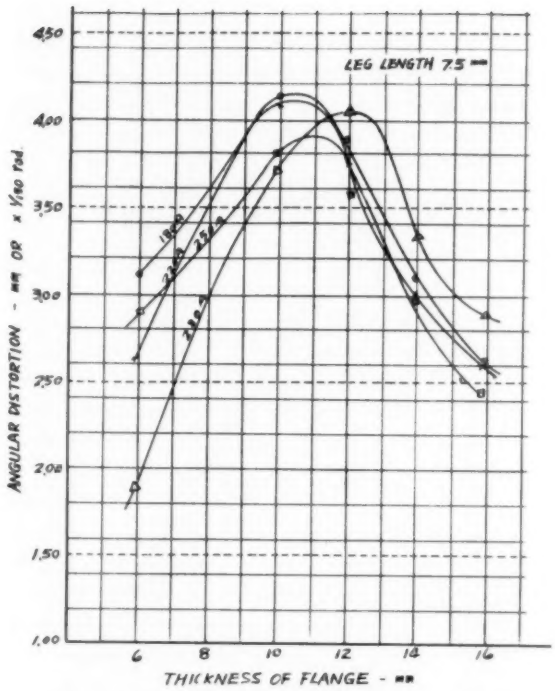

Fig. 9 Curves of angular distortion versus flange thickness, leg length 7.5 mm

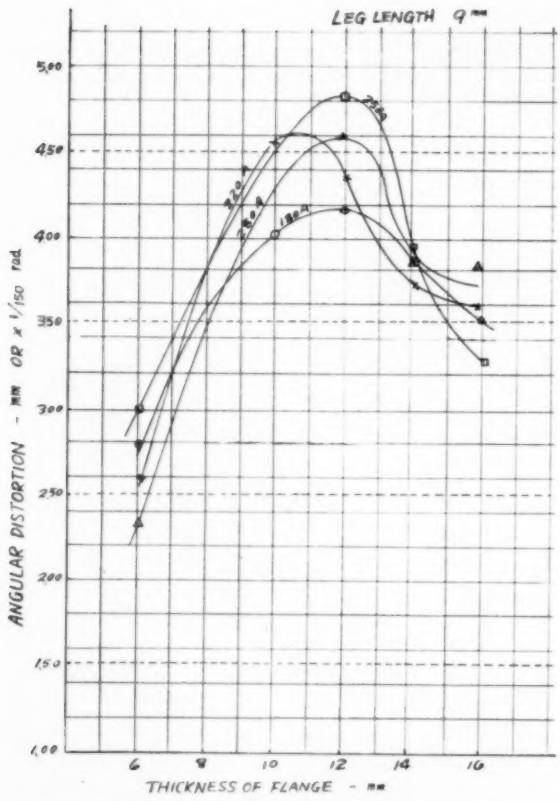

Fig. 10 Curves of angular distortion versus flange thickness, leg length 9 mm

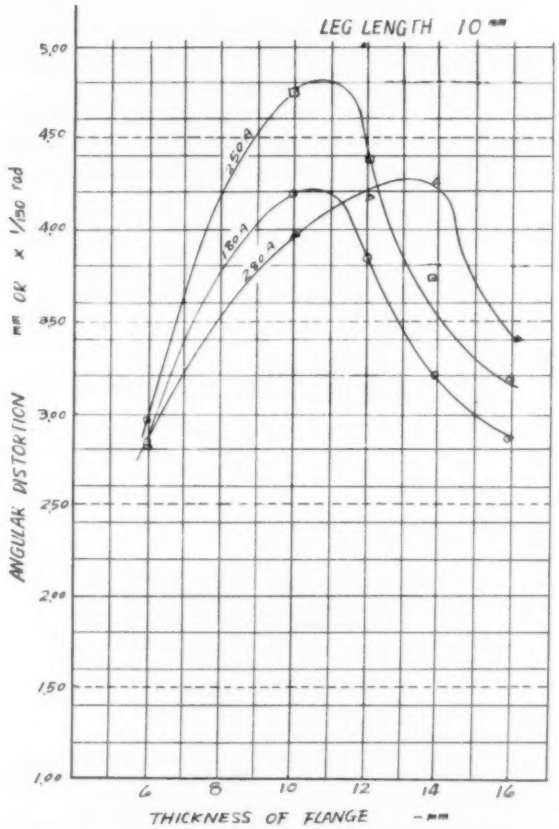

Fig. 11 Curves of angular distortion versus flange thickness, leg length 10 mm

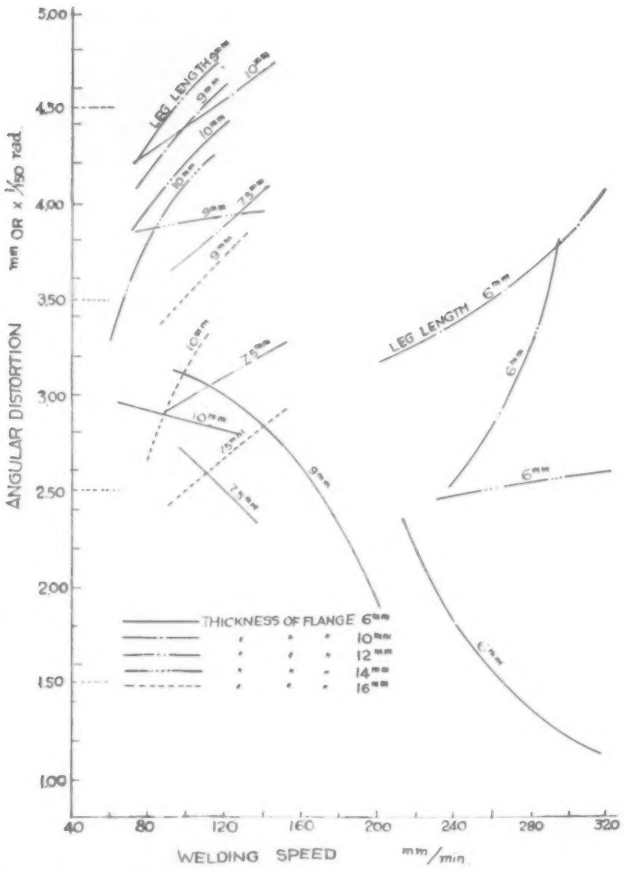

Fig. 12 Curves of angular distortion versus welding speed

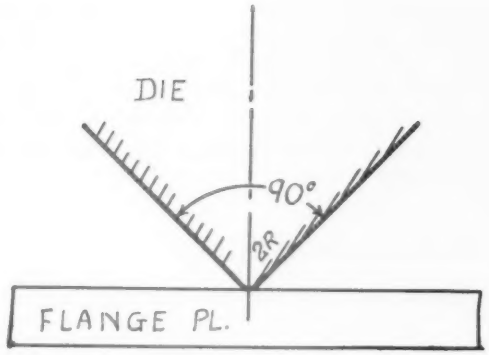

Fig. 13 Form of die for hydraulic press used for setting plastic prestrain

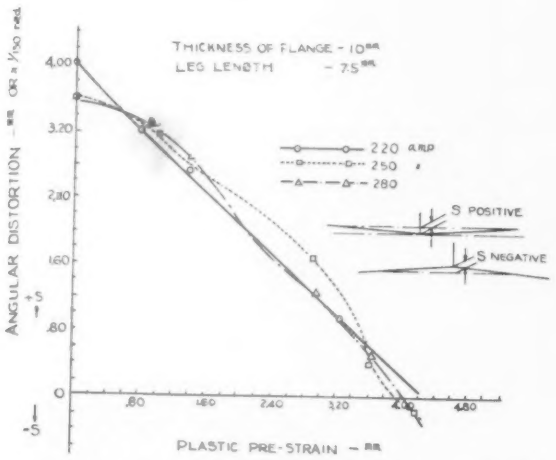

Fig. 14 Curves of angular distortion versus plastic prestrain, leg length 7.5 mm, flange thickness 10 mm. Other similar curves follow same denotation of sign of angular distortions as shown here

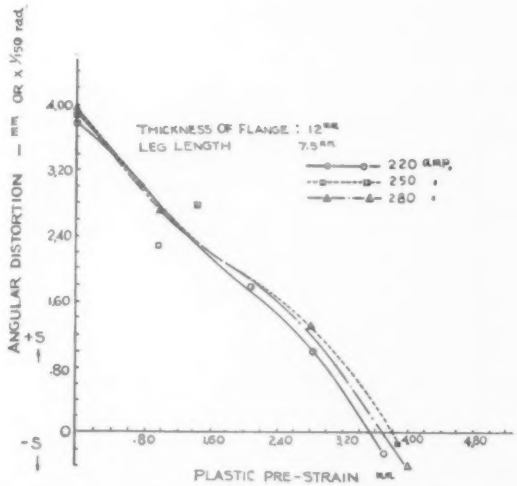

Fig. 15 Curves of angular distortion versus plastic prestrain, leg length 7.5 mm, flange thickness 12 mm

Fig. 12). Flange thickness of 6 mm showed a reverse phenomenon, and less angular distortion was found at higher welding speeds or higher amperes.

2.3 Considerations of Angular Distortion

Temperature rise is different in front of the heat source from that behind the source, which causes flange to distort during welding; the greater the difference of temperature the greater degree of distortion. Temperature distribution determines the rigidity of the affected zone. Co-authors assumed that, based on experimental results, little angular distortion would show on thinner flanges, in which case rigidity and temperature difference as well would show little, and for thicker flanges bending moment would be greater due to greater temperature difference; however, rigidity would show less decrement and would indicate little angular distortion. Within this experiment, flange thickness between 10 and 12 mm showed maximum angular distortion and could be considered as the intermediate between the two cases just mentioned above.

3. ANGULAR DISTORTION UNDER PLASTIC PRESTRAIN

One of the means of avoiding angular distortion in horizontal fillet welding is to give the flange plate in question a plastic strain in the opposite direction of distortion prior to any welding. This method has been applied to hull work in shipbuilding and bridge

construction projects, and is considered useful, as residual stress by this method shows less than that of constrained work. However, no statistical research has been done to determine quantity of prestrain sufficient to eliminate angular distortion after welding, and individual experiments for each project were made to determine the quantity of prestrain.

3.1 Method of Experiment

Testpieces of same material and size, and same method of measurement of distortion as stated in Chapter 2 were applied to this experiment under 24 different combinations of welding conditions namely, leg lengths of 6 and 7.5 mm, amperes of 220, 250 and 280, and flange thicknesses of 10, 12, 14 and 16 mm. Prestrain was applied by hydraulic press with a die shaped as shown in Fig. 13.

3.2 Experimental Results

Curves of angular distortion versus plastic prestrain

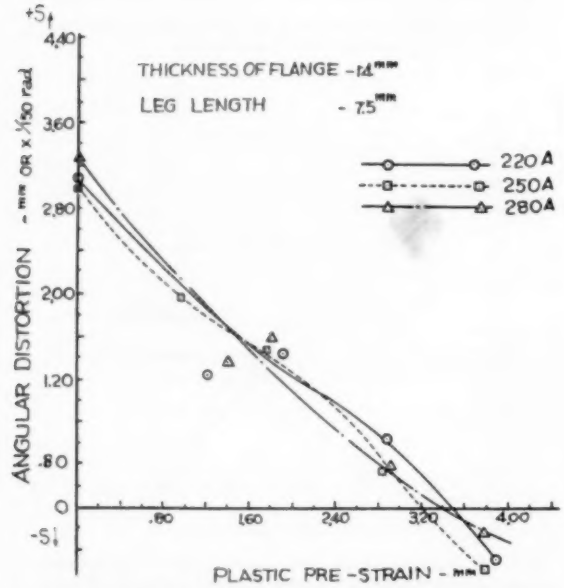

Fig. 16 Curves of angular distortion versus plastic prestrain, leg length 7.5 mm, flange thickness 14 mm

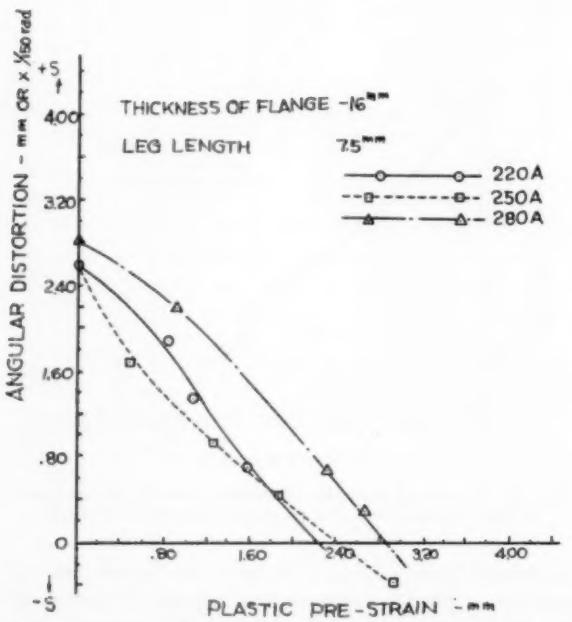

Fig. 17 Curves of angular distortion versus plastic prestrain, leg length 7.5 mm, flange thickness 16 mm

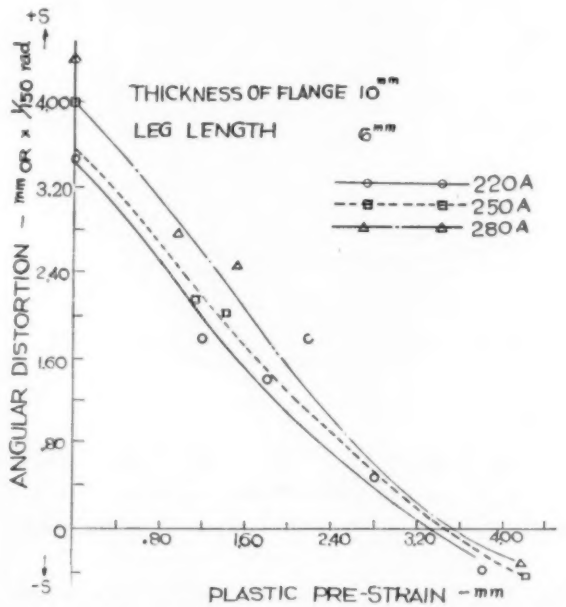

Fig. 18 Curves of angular distortion versus plastic prestrain, leg length 6 mm, flange thickness 10 mm

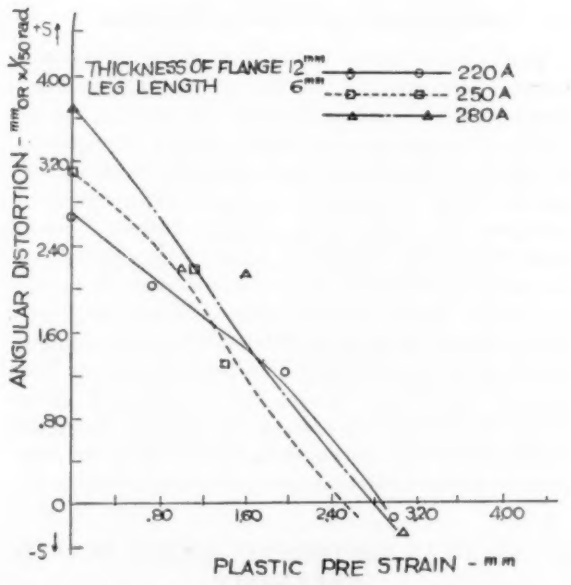

Fig. 19 Curves of angular distortion versus plastic prestrain, leg length 6 mm, flange thickness 12 mm

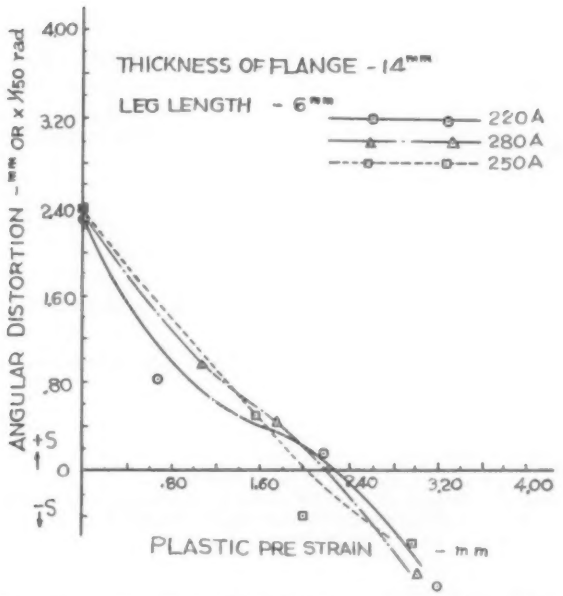

Fig. 20 Curves of angular distortion versus plastic prestrain, leg length 6 mm, flange thickness 14 mm

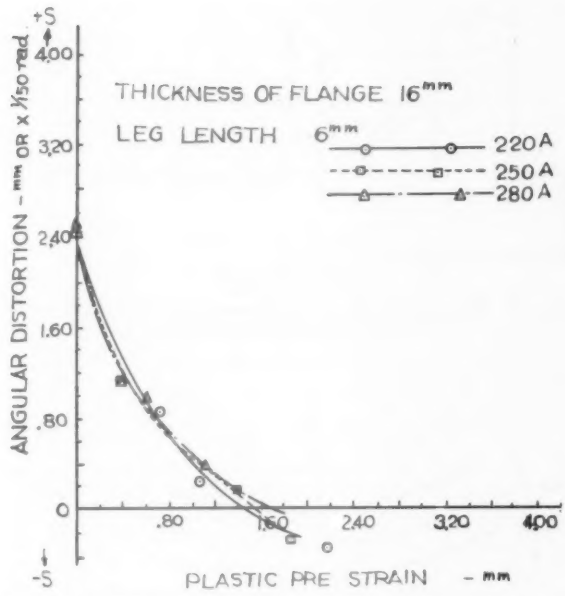

Fig. 21 Curves of angular distortion versus plastic prestrain, leg length 6 mm, flange thickness 16 mm

are shown in Fig. 14 through 21. Positive angular distortion S shows where prestrain was insufficient and negative excess. Then, to obtain zero angular distortion after welding the right prestrain value is indicated on the abscissa where these curves intersect. Prestrain of approximate equal quantity as free angular distortion was required for all flange thicknesses in the case of leg length 7.5 mm, and less prestrain than free angular distortion for plate thicknesses in excess of 12 mm in the case of leg length 6 mm.

Let

D_f = value of free angular distortion.
D_e = value of required prestrain under similar conditions as above.

then

$$\eta = \frac{D_e}{D_f} \times 100\%$$

Relations of η and flange thickness are shown in Figs. 22 and 23. Magnitude of plastic prestrain was found to be smaller than that of free angular distortion with increasing flange thicknesses at smaller leg lengths.

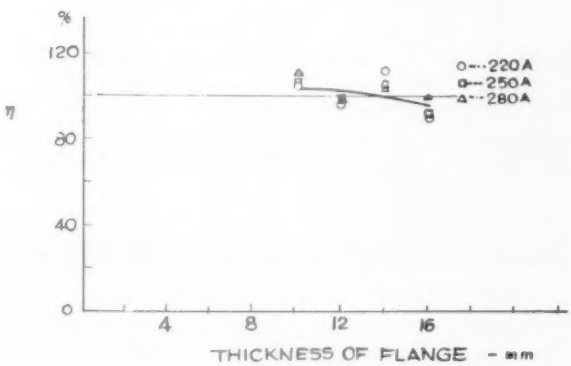

Fig. 22 Curve of flange thickness versus leg length 7.5 mm, $\eta = (D_e/D_f) \times 100\%$, where D_e is suitable value of plastic prestrain to avoid angular distortion, and D_f is value of free angular distortion under same conditions as above (leg length, flange thickness, current, etc.)

3.3 *Considerations of Plastic Prestrain*

Effects of plastic prestrain upon angular distortion are discussed here.

(*a*) Hardening of flange by cold working is considered rather small.

(*b*) Residual stress (of flange) caused by plastic bending, of inappreciable amount has minute effect upon angular distortion since heat of welding influences this residual stress.

(*c*) Effect of curvature of flange caused by plastic prestrain.

1. Consider the case of an arbitrary shrinking force.

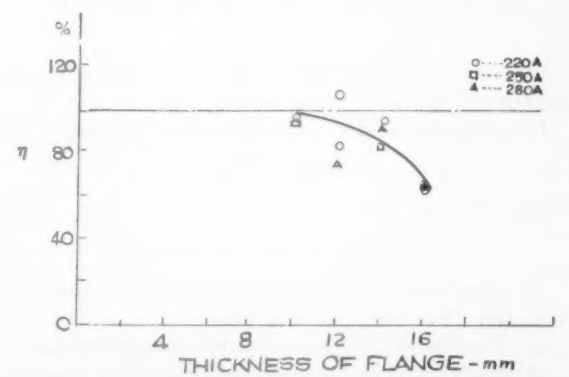

Fig. 23 Curve of flange thickness versus η, leg length 6 mm

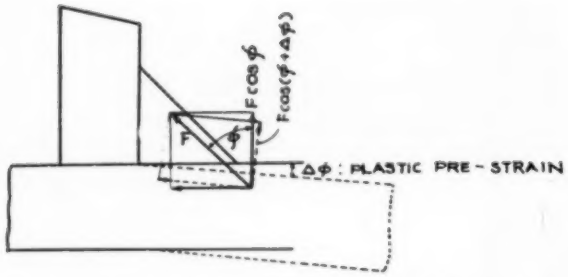

Fig. 24 Change of effective component of shrinking force caused by plastic prestrain

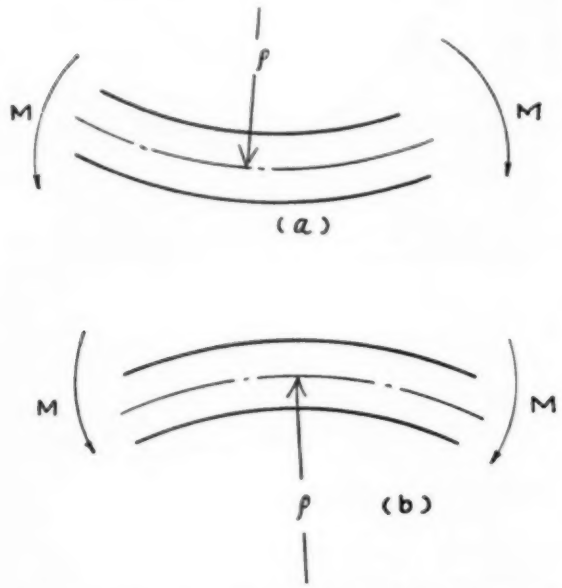

Fig. 25 Form of bending beam and bending moment

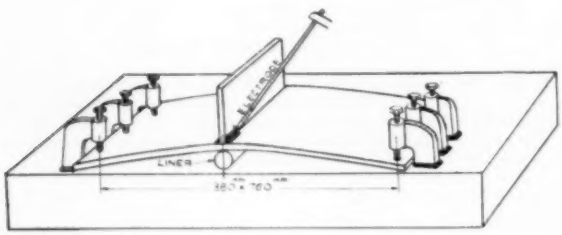

Fig. 26 Apparatus of effecting elastic prestrain

Where arbitrary contraction force = F and effective component of $F = F \cos \phi$, see Fig. 24.

Let prestrain = $\Delta\phi$. Then, effective component is:

$$F \cos (\phi + \Delta\phi)$$

When, $\Delta\phi > 0$

$$F \cos (\phi + \Delta\phi) < F \cos \phi$$

As noted, effective bending (contraction) component decreases when prestrain is applied.

2. Consider weld portion of flange as a curved bar.

When a curved bar is subjected to bending moment M type (a), as shown in Fig. 25, expresses less deflec-

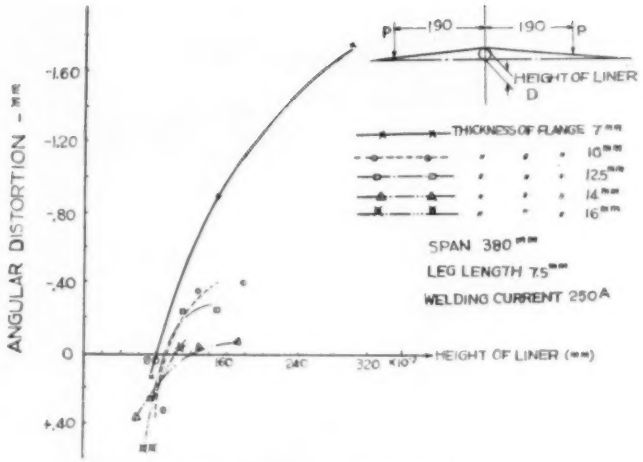

Fig. 27 Curves of angular distortion versus liner height for elastic prestrain (span 380 mm)

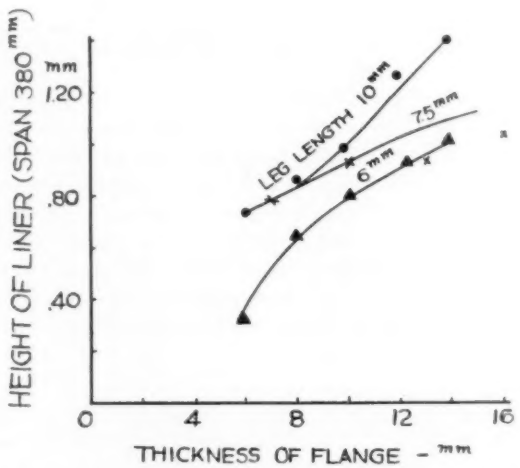

Fig. 28 Curves of flange thickness versus liner height for avoidance of angular distortion (span 380 mm)

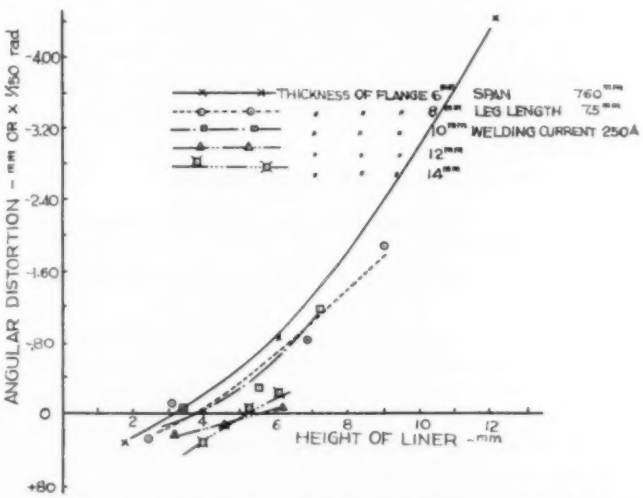

Fig. 29 Curves of angular distortion versus liner height for elastic prestrain (span 760 mm)

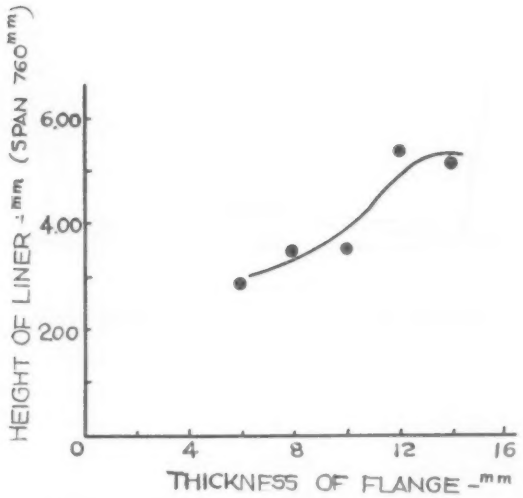

Fig. 30 Curves of flange thickness versus liner height for avoidance of angular distortion (span 760 mm)

tion than (*b*), where M has same value for both types.*

This type (*a*) corresponds to a flange being subjected to plastic prestrain.

Thus, when subjected to plastic prestrain, major factors as stated in paragraph (*c*) is considered to have attributed less angular distortion than free angular distortion under same conditions.

4. ANGULAR DISTORTION UNDER ELASTIC PRESTRAIN

A known method of avoiding angular distortion similar to that as stated in the preceding chapter is horizontal fillet welding done under elastic prestrain, and values of elastic prestrain have been assumed to suit each case by past experience. It was attempted to analyze this problem statistically and obtain quantitative relations applicable to ship yard practice.

4.1 Method of Experiment

An apparatus as shown in Fig. 26 was made and flange of a tee joint was put under elastic prestrain by bolting down both free ends. A round bar stock was used for the liner. Testpieces of 400 x 400 mm and 400 x 800 mm were used with flange thicknesses ranging between 6 and 16 mm. Spans of constraint set as 380 and 760 mm for widths of 400 and 800 mm, respectively, and welding done with leg lengths of 6, 7.5 and 10 mm using electrodes MS152 diam 6 mm (equivalent to E6020) and current 250 amp. Distortion measurements were taken after weldments were cooled down to room temperature and released from constraint.

4.2 Experimental Results

Relations of flange thickness and liner height, in Figs.

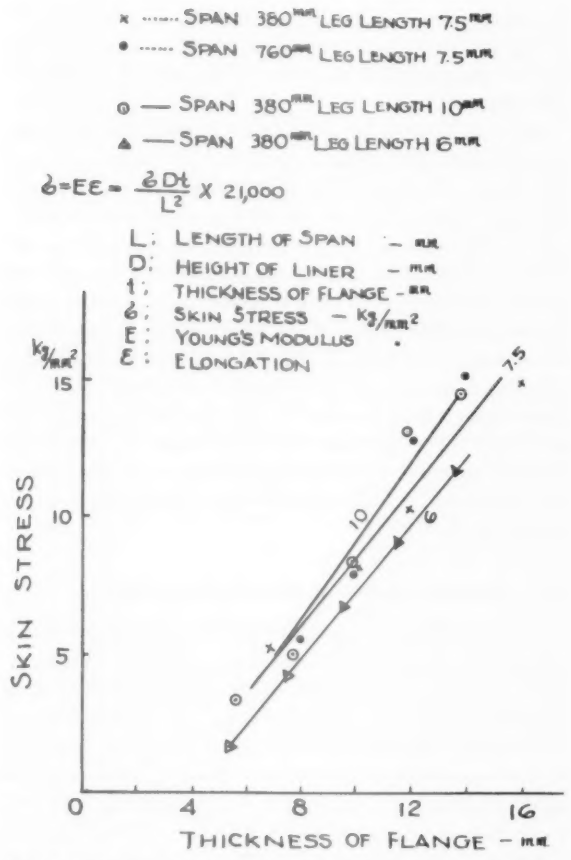

Fig. 31 Curves of skin stress of flange versus flange thickness for avoidance of angular distortion for elastic prestrain

Fig. 32 Example of horizontal fillet welding invert angles as stiffeners on panel

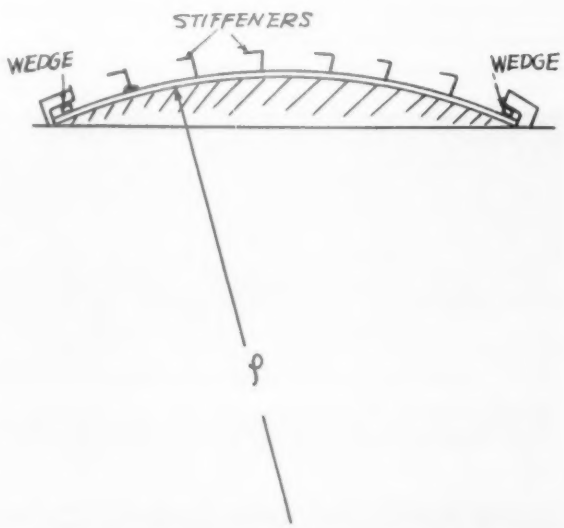

Fig. 33 Example of elastic prestrain being effected on flange to suit radius of curvature

* Timoshenko, S., *Applied Elasticity*, 1st ed., p. 261, 1925, Westinghouse Technical Night School Press, East Pittsburgh, Pa.

27 and 28, are shown with various leg lengths of 6, 7.5 and 10 mm, and span of constraint 380 mm. Figures 29 and 30 show similar relations with span of constraint 760 mm.

Skin stress on flange subjected to constraint prestrain for eliminating angular distortion was calculated from the above relations. Curves of skin stress and flange thickness, as in Fig. 31, showed proportional relationship. This shows a very interesting fact and curves are noted to have approximate similar gradient for each leg length irrespective of span of constraint. Then, when finding suitable values of elastic prestrain for tee joints being welded with flange thickness constant, leg length varying, and irrespective of span of constraint, only skin stress being applied needed be considered. Complicated problems of constraint for avoidance of distortion caused by welding within the conditions of this study are considered readily solvable from the simple relation expressed in Fig. 31.

4.3 Considerations of Elastic Prestrain

A welded flange released from constraint after welding straightens itself due to residual stress of weldment. And when leg lengths are made larger assumption of larger prestrain is understandable. As from the above experiment the required liner height is given from the skin stress versus flange thickness curve, irrespective of span of constraint. However, some constraints are not easily found by statical calculation as obtained above, because of indefinite constraints depending upon forms of material and strongbacks. This problem is solvable if further experiments are done by similar methods and stresses under constraint are found by calculations or experiments.

4.4 Application of Elastic Prestrain, Case 1

The application of elastic prestrain was found useful in solving constraint problems of complicated nature, since relationship between flange thickness and skin stress is proportional as shown in Fig. 31.

Consider a case where stiffeners are being welded on a wall or panel, which is kept under prestrain while welding is done, see Figs. 32 and 33.

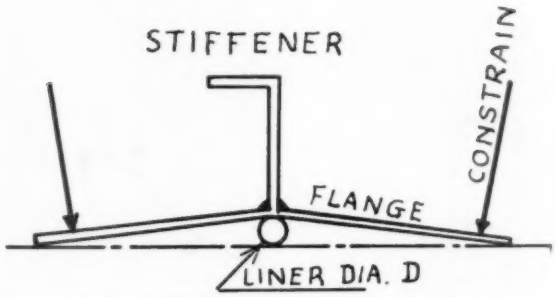

Fig. 35 Partial application of elastic prestrain

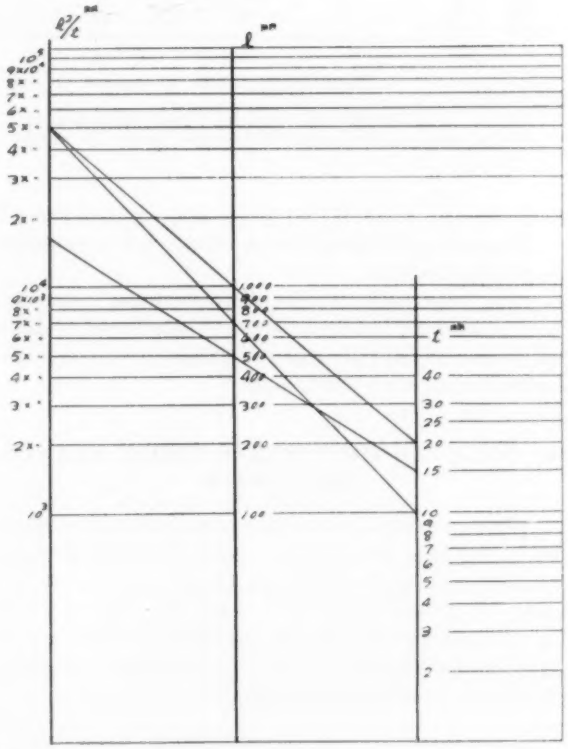

Fig. 36 Diagram I for obtaining suitable elastic prestrain, where t is flange thickness, l length of span

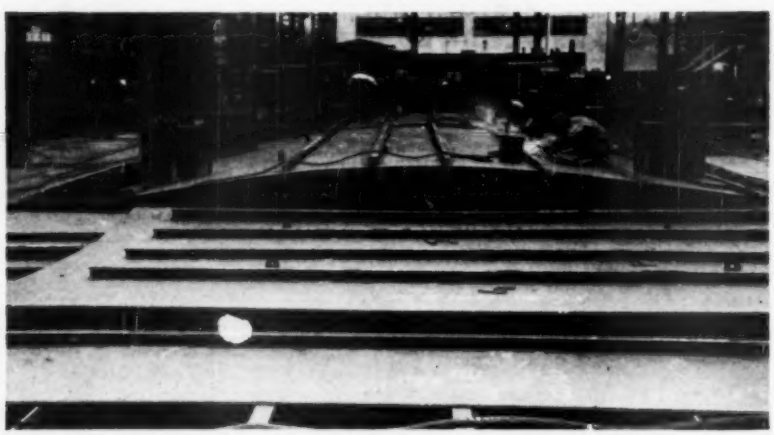

Fig. 34 Photograph showing application of elastic prestrain on welding coal bunker

Let skin stress = constant. Radius of curvature of weld fixture is:

$$\rho = \frac{Et}{2\sigma}$$

where:

t = plate (flange) thickness of panel, mm.
E = Young's modulus, kg/mm².
σ = skin stress, kg/mm².

From Fig. 31, skin stress σ is calculated where plate thickness and leg length are given. And radius of

curvature ρ is readily obtained if Young's modulus is known.

Actual Example:

Let plate thickness t = 9 mm; leg length = 6.5 mm. From Fig. 31, skin stress σ = 8 kg/mm²; E = 21,000 kg/cm²; thus,

$$\frac{E \cdot t}{2} = \frac{21{,}000 \times 9}{2 \times 8} = 11{,}800 \text{ mm}$$

A weld fixture was made so that panel was given the required radius of curvature 11,800 mm, and results were found satisfactory when this was applied to an experimental box girder and a coal bunker. (See Fig. 34.)

4.5 *Application of Elastic Prestrain, Case 2*

Curves as shown in Fig. 36 through 38 were prepared to aid prestrain calculations as in a case where each fillet weld was put under constraint, see Fig. 35.

Values of l^2/t and σ from Figs. 36 and 37, respectively, are obtained where flange thickness t and span of constraint l and leg length are given. And Fig. 38 shows suitable height D of liner from known valves of l^2/t and σ.

Application of this method of using elastic prestrain to eliminate distortion caused by welding proves to be very useful and helps to save labor costs for straightening of welded structure. Method as explained in Case 1, especially, is comparatively simple and if applied on production welding with same flange thickness, leg length, etc., a considerable amount of man-hours for straightening operation could be saved.

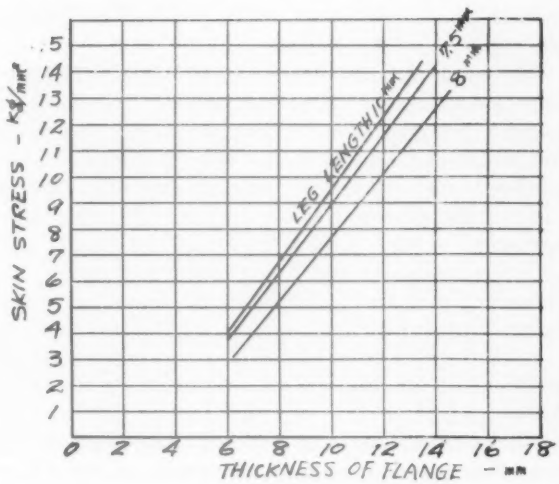

Fig. 37 Diagram II for obtaining suitable elastic prestrain

5. CONCLUSION

The above experiment resulted in the following conclusions.

(*a*) Free angular distortion occurs in the vicinity of 10 mm around the heat source (center of web).

(*b*) Less angular distortion occurs when electrodes of larger diameter are used in one-pass fillet welds than multipass using electrodes of smaller diameter.

(*c*) Free angular distortion is proportional to logarithmic value of weight of deposited metal.

(*d*) Maximum value of angular distortion is found on weldments of flange thickness between 10 and 12 mm.

(*e*) Less free angular distortion appears at greater welding speed on flange thickness of 6 mm when leg length is kept constant. Angular distortion tends to increase on plate thickness in excess of 10 mm under similar conditions.

(*f*) Suitable value of plastic prestrain to avoid distortion is comparatively smaller than that of free angular distortion when flange thicknesses are comparatively greater than leg length.

(*g*) Skin stress is proportional to flange thickness when under elastic prestrain.

6. SUMMARY

Welding conditions described in this research were chosen from practical hull welding conditions mostly used in shipbuilding. It is noted that application free

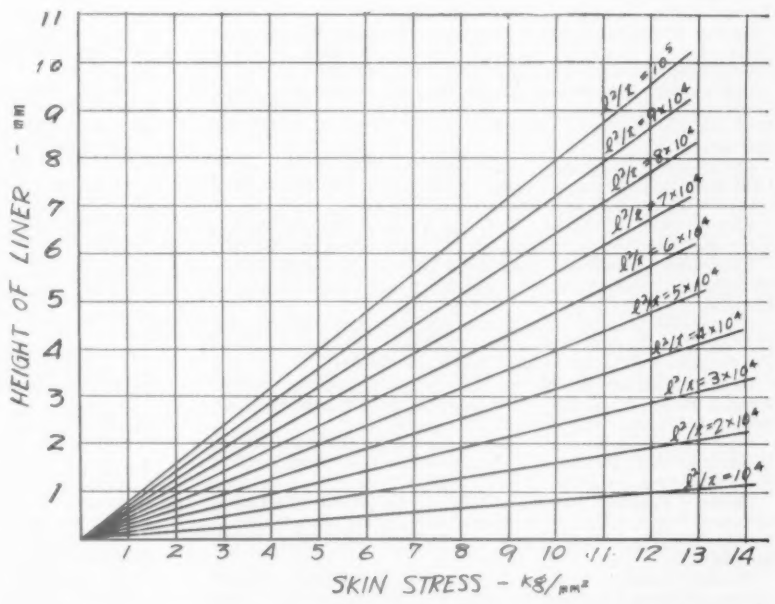

Fig. 38 Diagram III for obtaining suitable elastic prestrain

from this limitation would not be practical and is considered as another problem.

The purpose of this research was to find out and determine quantitatively what effects various factors had on angular distortion resulting from horizontal fillet welding which is extensively used in shipyard practice, and, further, advance from the conventional procedure of determining prestrain values on past experience, and determine suitable values of plastic and elastic prestrain as means of eliminating angular distortion.

Since, during this research, it was noted that many factors had direct influence on the subject and its interrelational effects, experiments in this research were all held under limited conditions, such as flange thickness, leg length and welding current.

The co-authors do not consider that the above results are sufficient and satisfactory. However, curves of data compiled from experiments of one-pass fillet welds using electrodes for this purpose showed less deviation than multipass fillet welds, and made analysis easier and facilitated foresight of trend of angular distortion with comparatively less experiments.

The co-authors intend to extend their research and work further on this one-pass fillet welding.

ACKNOWLEDGMENT

The co-authors desire to thank Assist. Prof. L. E. Wagner of the University of Michigan who will present this paper, on behalf of the co-authors before the 1954 AWS National Fall Meeting, and the Management of the Yokohama Shipyard & Engine Works, Mitsubishi Nippon Heavy Industries, Ltd., for their permission of using illustrations and data, and F. R. Karasawa of the same firm for his translation of this paper.

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Fig. 1 The finished hopper car. All parts of this car are made and welded in the shop

Car Building on the T&P

The building of railroad cars in a converted steam locomotive repair shop

by Hugh D. Hollis

THE Texas and Pacific Railway Co. is in its 83rd year of operation. The territory served by the T&P stretches across the vastness of Texas and Louisiana. From El Paso, the "pass" to the Pacific Coast, it runs eastward across the West Texas Plains, the cattle ranges, through the wheat belt, industrial cities, oil lands, cotton country and the rich sugar cane region of Louisiana to New Orleans, the "gateway" to Latin America.

In the little East Texas city of Marshall, near the mid-way point of the Texas and Pacific system, the principal locomotive and car repair shops were originally located. Marshall is an old railroad town. It would be more accurate to call it an old Texas and Pacific town. The T&P General Stores and Reclamation Plant also are located here and to a large extent Marshall's economic well-being depends upon these railroad shops and stores.

When the Diesel electric locomotive replaced the steam locomotive on the Texas and Pacific, our Lancaster Yard at Fort Worth became the site of our main Diesel repair shop. Consequently, this move left the railroad with a Boiler Shop, Blacksmith Shop, Machine Shop and Steam Locomotive Erecting Shop at Marshall which would be idle unless something were done. Besides these shop buildings and facilities, loyal and valued employees, an efficient shop and engineering organization had to be considered.

The railroad management decided that something should be done and the plan was to add car manufacturing to the repair function and thus capitalize upon the valuable assets in this location.

In a relatively short time, the Marshall Shops, with the assistance of welding suppliers' servicemen, converted a steam locomotive repair shop to an efficient car-building plant. Fortunately, the welding art had reached a stage where good cars could be built efficiently. Naturally we had to walk before we could run. The first car program was the building of 100 flat cars and 150 gondola cars. Maybe the word "building" is too ambitious, possibly assembling would be better.

For the flat car we purchased cast-steel underframes, brakes, truck parts, wheels, etc., and assembled the car. For the gondola car, truck parts, brakes, fabricated underframes, sides and ends were purchased and the car was put together. This first program was completed on schedule and at a definite saving over cars purchased from the car builder. More desirable still, it gave us valuable experience in design, planning and operating technique. The next program of 250 gondola cars was more inclusive. We obtained the truck parts and car ends as before but purchased rolled shapes, plates and bars and fabricated the underframe and sides ourselves. Since that time we have built 200 hopper cars, two hundred and fifty 40-ft 6-in.

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AAR box cars and in 1955 we will build one hundred and fifty 40-ft 6-in. AAR box cars, fifty 50-ft 6-in. box cars and 15 cabooses. The plan now is to continue to build our own cars in the future.

I am confident that a properly designed and properly welded car will give as good if not better service than a riveted car. The design must take into consideration the peculiar properties of welded construction. The rigidity of the welds, the internal stresses resulting from shrinkage and the ease and efficiency with which the welds can be made are all important items. Our first and foremost endeavor was to build a strong car. Present railroad operation, with powerful Diesel locomotives and long trains, requires design strength that a few years ago would have been considered extravagant. There is no economy in building a cheap car that will not stay off the repair tracks and out of the shops. Some railroads have learned this to their sorrow. For instance, in box car construction, we feel that a strong floor, strong side sills, good heavy bolsters and diagonal end braces and substantial reinforcements over the door are all worth more toward keeping cars in service where they will earn revenue than the slight increase in car cost due to these additions above the minimum AAR requirement.

Fig. 2 The "Z" bar section of the center sill is secured in this jig, and then then welded together using a submerged arc automatic welding machine

How to take care of rigidity of welded construction and internal stresses is something we have had to learn from the study of the failures of welded cars now in service. The first welded cars built failed because the builder cheapened the construction and made the mistake of misjudging or underestimating the stresses due to impact. This, in my judgment, resulted in failures that were blamed on welded construction but which in reality were due to faults in design.

Welds must be properly made. That is axiomatic. We purchase structurel steel of not more than 0.20 carbon content. You have to waive the physical requirements of the specification or the steel mills cannot furnish this material but we consider its weldability is more important than the minimum tensile strength. Undercutting must be held to a minimum and cleanliness of the welding joint is not only a virtue, it is a necessity. Welds must be kept away from the corners of the center sills and draft members must be welded to center sills with as perfect welds as possible. Transverse welds between the draft lugs and the center sills must be avoided at all costs. Bolster cover plates must be designed to reduce the stress concentrations where they are welded to the center sills. The car design must be such that the car can be efficiently built.

The greatest possible use of commercial shapes is required. This tends toward economical construction. Irregular shapes that must be cut and welded should be kept to a minimum, consistent with lightweight and strength requirements. Shop methods must be studied and constantly improved. The proper jigs are very important.

In the midst of the Diesel conversion, and when we knew the steam facilities would not be needed, it was necessary to have a new power plant. We decided to install steam generators instead of conventional boilers and the question of steam demand had to be decided. In the motive power Blacksmith Shop we had a large

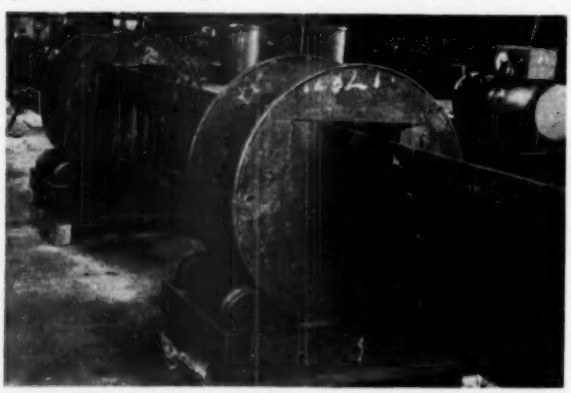

Fig. 3 This fixture is used for turning the center sill when the center filler is applied. A flexible welder is used in this operation

Fig. 4 A flexible welder is particularly well suited for this center sill operation, because it is easy to operate in hard-to-reach places

5000-lb steam hammer which required a large volume of steam and this meant an extra investment for steam capacity if we were to use it. We installed the extra steam generators and events have proved it was a wise move.

With this 5000-lb steam hammer we shape second-hand axles into bars and flats from which we flame-cut in the Blacksmith Shop brake levers, coupler carriers, draft gear filter blocks, etc. We have an Ajax Forging Machine with which all grab irons, brake rod jaws, brake pins, etc., are made.

The Boiler Shop has been converted to a Fabrication Shop. We had one mechanical press brake but since we started building cars we purchased a hydraulic press brake and large plate shears. We have another shape-cutting machine in the Boiler Shop and this machine, together with the shears and one of the presses, is located under a 25-ton traveling crane. The area under this crane is not very large and it has taken quite a bit of ingenuity to efficiently route the work through this department.

We had some trouble getting our men to properly clamp sheets for stack-cutting on the flame-cutting machine but when we finally did get the trouble corrected, the operation did a beautiful, uniform job and saved time and money.

All subassemblies such as bolsters, crossmembers, brackets, etc., were assembled in jigs and submerged arc welded. The bolster jig for the gondola car was arranged for clamping with air as this saved time and made the clamping more uniform.

Our program that required the greatest ingenuity in jig construction, fitting and welding was the 200 hopper cars. These cars were built for our subsidiary, the Texas–New Mexico. Since this car design has more curved surfaces and irregular welds than gondola or box cars, the explanation of its construction will possibly be the most enlightening. We built four of these cars per day.

Figure 1 shows the general arrangement of the car as built. The main draft member and the backbone of the car is the center sill which is a continuous rolled section passing lengthwise through the car, below the floor and between the six hoppers, three on each side. The hoppers are irregular surfaces with sloping and curved sheets that must be fitted and welded together. As we progress with our explanation, further details of the car will be easily understood.

Figure 2 shows the jig for welding the center sills. The center sills which are rolled in two "Z" sections can be seen on the other side of the jig. The zees are clamped in the jig by the air clamps and the hose is inflated, forcing the flux up under the joint between the zees to be welded. A submerged arc automatic welding machine welds the two zees together the full length. A carriage for the welding machine rolls on the sills, not on a separate track. The AAR requires 100% penetration for a portion of this weld in the vicinity of the bolsters and we had no trouble meeting these requirements.

Fig. 5 Submerged arc-welding machine fillet welds a center plate to a bottom bolster plate at an average speed of 14 ipm

Fig. 6 General view of side jig. Sides of car are assembled and welded on this jig

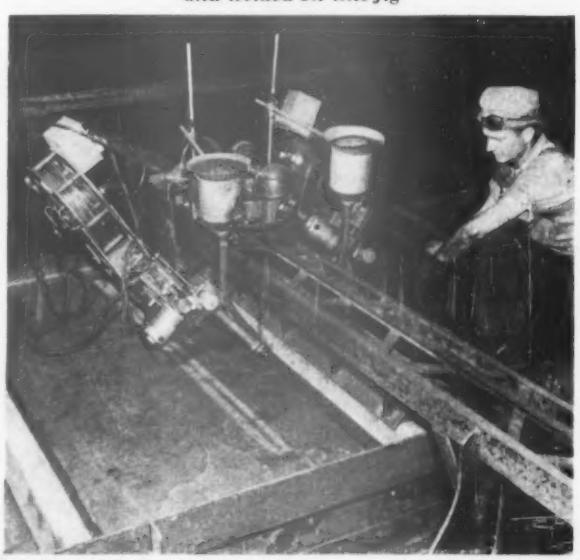

Fig. 7 Cross carriage and clamp for automatic submerged arc welders used for welding side stakes. Welding speeds average 43 ipm

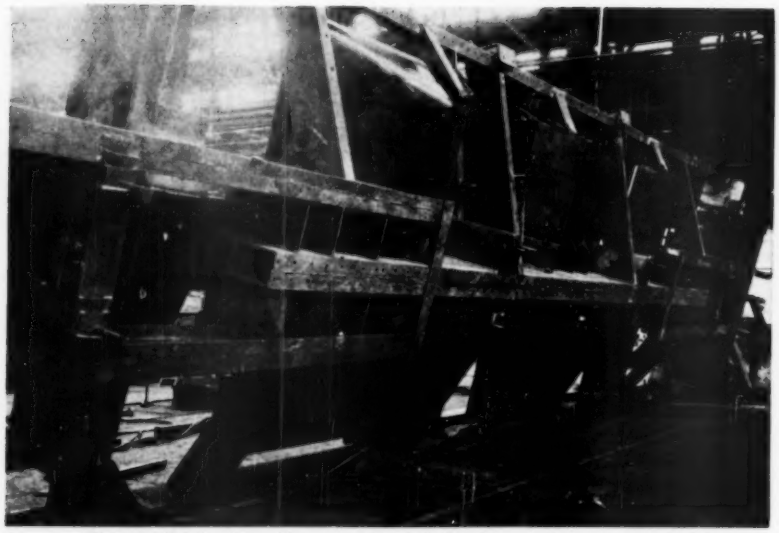

Fig. 8 This is the back or bottom view of the jig used to secure the hopper sections of the car. Here the hoppers are in place

Figure 3 shows the jig for positioning the center sill to weld on the draft attachment and other parts. The underside of the weld uniting the two zees can be clearly seen. This jig permits the sill to be rolled to any position for downhand or submerged arc welding.

Figure 4 shows a method used to weld the draft attachment securely to the center sill. The longitudinal slots cut through the center sill are located by a templet while the sill is in the first jig. Consequently, all are sized and spaced alike. I might mention that the welds are longitudinal in the center sill and that the total welds have 50% more cross-sectional area than the usual riveted assembly.

Figure 5 shows the assembly of the body center plate and the bottom bolster cover plate. The automatic submerged arc welder was used wherever possible because it made a more consistent weld and to some extent eliminated the human element.

Figure 6 is a general view of the side jig. The sides of the car were assembled and welded on this jig. The automatic machines run on a track and weld the post on both sides. This same carriage clamps the posts accurately and firmly in place on the sides. The third automatic machine welds the top and bottom angles to the sides. After the welding on this side was completed, the sides were turned over and the top and bottom angles welded on the other side. Two of these jigs were used. Both jigs were mounted on wheels and pulled into the adjacent bay for loading. The pre-cut and fabricated parts were stored in that area. The jigs were easily and efficiently loaded and the parts clamped in place, preparatory to welding. We attempted to pull the jigs under the automatic welding machines and hold the machine stationary but this was a failure because of the irregular travel of the jig. It just would not work.

None of these figures shows the winches that pull the jigs. These winches were made from the pin-turning attachment of a steam engine quartering machine.

Figure 7 shows a close-up of the cross carriage and clamp for the automatic submerged arc welders used for welding the side stakes. Holes in the jig position the cross carriage and thus accurately locate the side stakes. There were a number of other jigs that were used to assemble the ends, hopper doors, hopper frames, bolsters, etc. All of these parts were finally brought together on the master assembling jig shown in Fig. 8.

Figure 8 is an underneath view of the jig rotated almost 90 deg. One center plate and the lower part of the hopper chutes are visible. This jig was built of secondhand materials but you can see that it is very strongly and rigidly constructed. Notice the large hold-down pins with tapered keys. These pins lock the center sill in place.

Figure 9 shows the opposite side of this jig in the same position as Fig. 8 and with the same car parts on it. The center ridge covers the center sill and the slope sheets and chutes are plainly visible. Notice the bolsters made out of 21-in. "I" beams with the top flanges bent.

Figure 10 shows the turning mechanism for the main assembly jig. This mechanism gave us quite a bit of trouble. It had to be much more powerful than we anticipated and we broke it a couple of times before it was finally satisfactory. The two large gears were

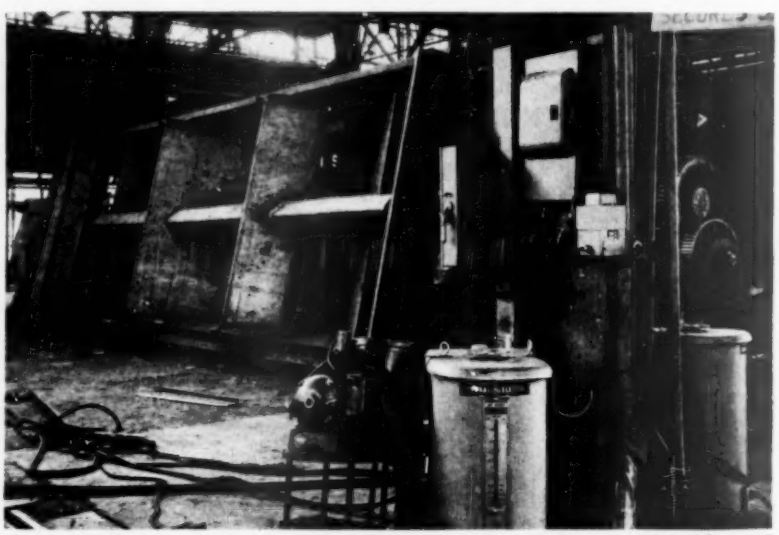

Fig. 9 This is the underframe jig. The car is turned almost on its side, and the hoppers, hoods, crossridge and "I" beams are in place

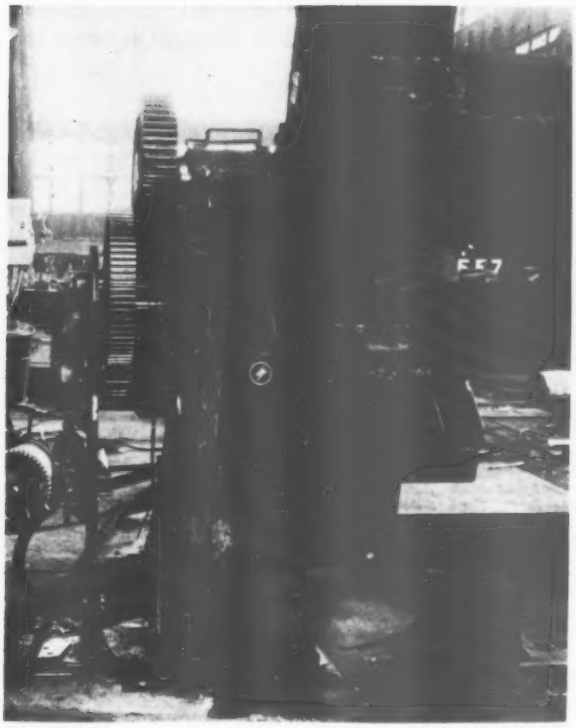

Fig. 10 This power unit is used to turn the car from side to side in order to position it for different welds while it is being fabricated

scrap Diesel locomotive gears. We couldn't even keep the Diesels out of our car-building program.

Figure 11 shows the semiautomatic submerged-arc-welding machine being used to weld the hopper and slope sheets. Notice the jig made of wooden strips to help the workman steady himself on the slope and to hold the melt over the welding arc.

Figure 12 shows an automatic submerged-arc-welding machine being used to weld the slope sheets to the side sheets.

Figure 13 shows this same machine mounted on a jig and welding the center ridge to the inner sheet of the hopper chute.

Fig. 11 Flexible welder is used to weld hopper and slope sheets. Granulated material is held in place on the slope by an asbestos covered board

Fig. 12 This submerged arc machine is making a fillet weld where the crossridge sheet overlaps the side sheet. The machine covers 61 ft at an average welding speed of 35 ipm

I purposely have not mentioned a very important fact that by now is obvious; i.e., that every effort was made to use submerged arc welding. Parts were fitted to the main jigs and tack welded together by hand and short inaccessible welds that could not be taken care of automatically, were hand welded. However, hand welding was used as little as possible and with very few excep-

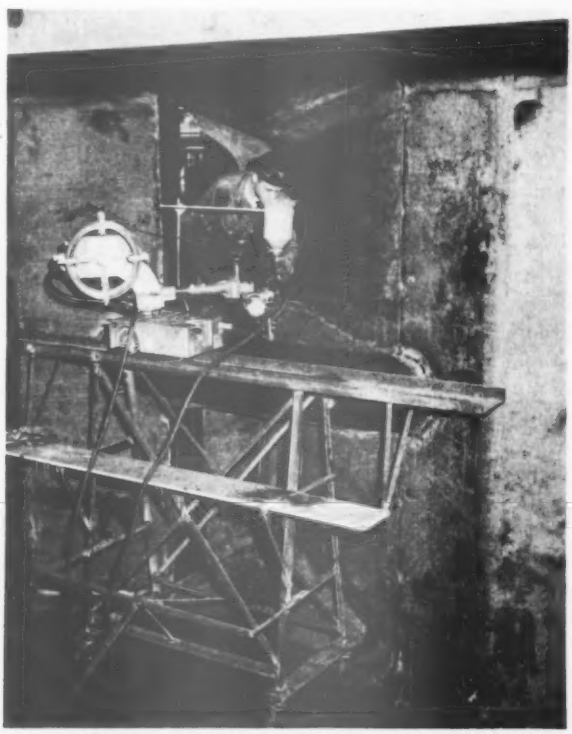

Fig. 13 In this operation the hood and hopper sheet are welded together at the same time they are welded to the center sill. Welding speed is 21 ipm

tions was done in a down-hand position. Submerged arc welding makes a stronger and cleaner weld. It does not depend so much on the skill, judgment and integrity of the welder. We have had to use men not trained as competent welders and the submerged arc weld has been our answer.

New Concepts in Spot X-Ray of Welded Structures

Spot radiographs, 3 in. in diameter, with portable X-ray equipment are now replacing the trepanning of welds in oil-storage tank construction

by Harold Hovland

THE API "Committee on Standardization of Tanks for Oil Storage" has recommended for adoption the use of 3-in. spot radiographs in lieu of trepanned plugs for weld examination of oil-storage tanks. This marks the beginning of a new concept of spot radiographic procedure. To accomplish this meant the development of extremely portable X-ray equipment that could be operated by nontechnical people. It furthermore meant processing facilities that would eliminate the need of conventional darkrooms on construction jobs. It meant overcoming problems of radiation safety hazards. The problems and the approach to the solution will be discussed.

The petroleum industry spends many millions of dollars each year for welded structures ranging from complex refinery structures to pipeline and storage tanks. Spot radiography was first used on pipeline construction by one of our major oil companies in 1946. Since then every pipeline project of this company has had radiographic sampling. Our own organization has used radiographic inspection and weld control on over 20,000 miles of pipeline construction since 1946. It was only natural then that the petroleum industry with its radiographic experience in pipeline and refinery structures should explore the possibilities of replacing trepanning with a radiographic method.

Heretofore the accepted method of weld inspection on storage tanks was by trepanned plugs. Trepanning is usually referred to as a nondestructive test (WELDING HANDBOOK, Third Edition, p. 983). There are many who disagree. Recently the plug repairs on an oil storage tank were spot X-rayed and 93% of the repairs were found to be defective. The geometry of the void left by the plug makes good repair difficult. During the past three or four years there have been structural weld failures which in the opinion of competent observers were traceable to trepanning plugs for inspection.

Many engineers have been dissatisfied with trepanning for a long time. What were the factors that dictated its continued use? First, the equipment necessary to perform the trepanning is relatively inexpensive. Second, the trepanning can be performed by unskilled personnel without specific training. Third, the over-all cost of the trepanning inspection method of any given job is quite moderate. Fourth, it was a safe method from the standpoint of operating personnel.

Other methods of nondestructive testing have been tried but have been found wanting for either technical or economic reasons. It is obvious that any method of inspection which is to replace trepanning must be comparable from an economic standpoint and superior from the technical standpoint.

The advent of the atomic pile has brought to the nondestructive testing field several new radioisotopes. Many have suggested that these new isotopes are the solution to the problem of economics and portability of radiographic equipment. However, the problem would seem to be not so simply answered. The HANDBOOK of the AMERICAN WELDING SOCIETY, Third Edition, devotes an excellent section to weld radiography, pp. 970–990. Page 976 of the HANDBOOK states: "The low contrast levels obtainable with gamma rays, render them unsuitable for most weld inspection." Most steel thicknesses which we are called upon to examine range from 0.25 in. up to 2.5 in. and greater. Yet the great bulk of the work falls between 0.25 and 1.5 in. To maintain maximum defect perception the wave length must be varied to suit the thickness of steel we are to examine. With the gamma rays of radium or various radioisotopes we have no such control over wave length. The radia-

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Fig. 1 Illustrates compactness and portability

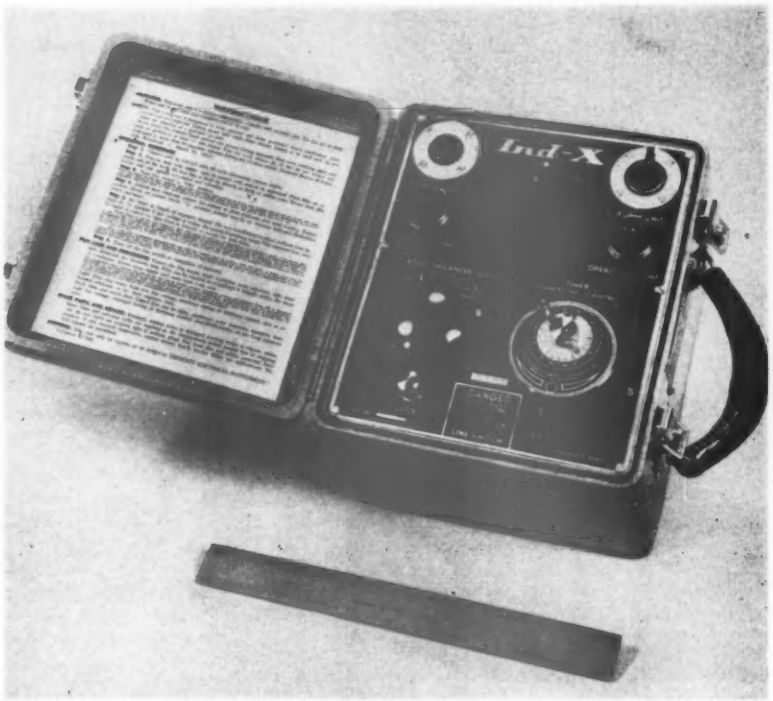

Fig. 2. Illustrates the Control Unit

tion from a given isotope remains the same and cannot be changed. Hence the radiographer is in the position of a photographer using a box camera. The only control he has is to change the type of film or to modify the processing conditions. One pays several hundred dollars for a good camera with variable lenses and shutter openings to be able to make pictures under the most variable conditions of light and subject matter. So it is in radiography. Since it is not practical or possible to have gamma-ray sources of given wave lengths for each steel thickness we examine, we find X-ray the most practical source or "camera" to use.

Most design and development work in X-ray equipment since Professor Roentgen's discovery in 1895 has been along medical lines. This meant, of course, that most X-ray equipment was designed for laboratory installation. With the recognition of X-ray as a means of weld inspection by the ASME Pressure Vessel Code in 1931 came some development of X-ray equipment for field use. Most of these developments, however, were modifications of medical X-ray equipment. It is interesting to note, too, that most X-ray film sizes used today are primarily designed on anatomical and not industrial requirements.

The greatest stimulus for the development of industrial radiographic equipment came with the advent of World War II and immediately following it. Real progress in design of X-ray equipment for field weld examination was made in 1947. At this time X-ray equipment designed to examine welding on pipeline construction was introduced. The original pipeline X-ray unit weighed 70 lb, with a length of 30 in. and a diameter of 10 in. Some idea of the progress in X-ray equipment development can be gained when one compares this with equipment of similar capacity which we used during World War II weighing over 600 lb and requiring a crane to be moved. However to fit the new concept of spot radiography this was not enough. In order to gain the portability and simplicity of operation necessary to economically replace trepanning it was necessary to revise our ideas of film sizes, X-ray and processing equipment. Some of the equipment and safety requirements are listed below.

1. *Compactness and Portability.* The Weld Inspector must be completely independent of crane service. He must be able to carry the equipment to the job and handle it on a scaffold.

Figure 1 illustrates equipment of this type.

2. *Simplicity of Control.* The wide use of the method requires that equipment be used by weld inspectors and not radiographers. Its operation must be easily understood by nontechnical people. Calibration of the control setting in terms of steel thicknesses with time and distance factors remaining constant achieve this goal.

Figure 2 illustrates such a control unit.

3. *Radiation Safety.* By limiting film size to a circle 3 or 4 in. in diameter, radiation protection becomes a simple matter without excessive weight. Thus the radiation hazard is reduced to a minimum. It is common knowledge these days that penetrating radiation, whether X-ray or gamma-ray, is biologically dangerous. Every possible precaution must be taken to prevent excessive radiation, not only to the radiographer but to other workmen and to the public in

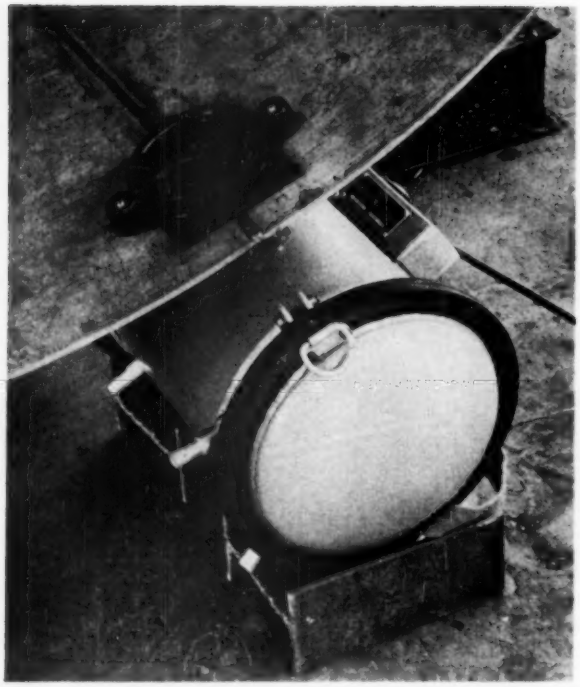

Fig. 3 Illustrates the position of an x-ray unit on a weldment. (Note the special film holder)

general. Permissible amounts of radiation which persons may receive are set forth in the U. S. Bureau of Standards Handbook 41. They should be studied and understood by anyone working with X-ray or gamma-rays. X-rays are emitted only at the actual time of exposure, while gamma-rays are emitted 24 hr per day. Gamma-ray sources are usually placed in lead containers for protection but the hazard is there as long as the source is active.

Figure 3 illustrates the position of the X-ray unit on a weldment.

4. *Small Film Size.* A 3- or 4-in. spot radiograph permits the use of processing kits that may be used in daylight, thus eliminating the need for bulky or costly darkrooms. This permits the radiograph to be processed on the job and information gained thereby to be made available immediately to the welding crew. The advantages of this processing procedure for controlling weld quality are extremely important.

Figure 4 is a reproduction of a 4-in. spot radiograph on a 0.25-in. thickness weldment showing cracks, slags and undercut.

Figure 5 illustrates complete processing kit that may be used on the job and requiring no darkroom.

5. *Cost Comparable to Trepanning.* If owners are to use this new method of spot radiography in lieu of trepanned plugs, the cost must be in line with that of trepanning. By limiting the film size and thus the radiation area, we reduce the physical size of the X-ray equipment necessary to perform this work. We are then able to provide the advantages of radiographic examination at a low cost and without interference with the fabrication process.

The ASME Code, Section UW-51, Paragraph F, requires that the distance of the radiation source to film be a minimum of seven times the thickness of the material examined. This is entirely proper for a structure being 100% radiographically examined, or even under the random radiography set forth under that Code. In 3-in. spot radiography we have a distortion factor of as much as 30%, due to the fact that the source-to-film distance is only three to eight times the material thickness. This factor must be taken into consideration when interpreting spot film radiographs. A compromise was necessary in order that we could retain the many other advantages of the radiographic method. This is not a radiographic method to replace that specified under ASME, Section UW-51 or UW-52.

Spot radiographs reveal far more of the internal weld structure than the trepane plug. It reveals a continuous section of welding 3 or 4 in. in length. This provides more accurate information for inspection purposes, but more important, if properly used, it provides a basis for control of weld quality. Most people in industry think of radiographs merely as an inspection record. However the greatest value of radiography is its ability to keep welding supervision constantly informed of the quality of the work. It enables the

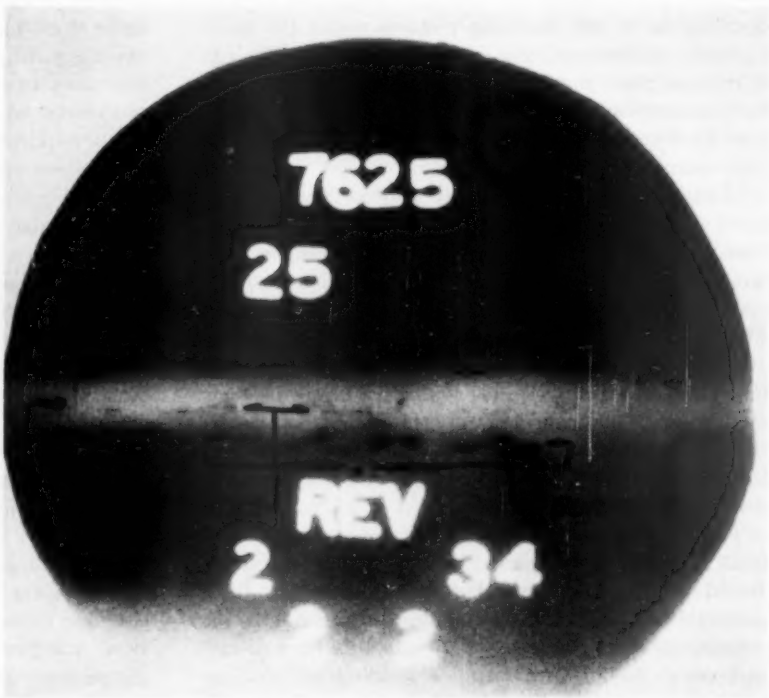

Fig. 4 Is a reproduction of a 4-in. spot radiograph on a 0.25 in. thickness weldment showing cracks, slags and undercut

Fig. 5 Illustrates complete processing kit

welder to see what he is doing and thus maintain a high level of quality. Our records indicate that over 50% of substandard welding observed, whether hand welding or automatic, is due to what we term procedural defects. In other words, these defects are not necessarily due to the ability of the individual welder. When the procedures are corrected the welding is acceptable. For this reason we find that an important phase of radiographic sampling is to detect trends toward improper procedure and correct them before unsatisfactory welding occurs.

From the radiograph one can determine not only the number and type of defects but any trend or tendency to depart from correct procedure. In weld control it is important to detect such trends before they result in unacceptable welding. For instance, a welder frequently will become careless in cleaning slag or in observing proper weld fit-up, or fail to adjust his machine setting correctly. Originally, such carelessness or error may not cause unacceptable welding, but experience shows that, if continued, defects caused thereby usually become more frequent and become more exaggerated. If not corrected they ultimately result in cutouts or repairs. The trend on a radiograph is a red flag to the radiographer. As soon as one is detected, successive radiographs of that particular welder's work are carefully examined to determine if the error is continuing and, if so, to immediately call it to the welding foreman's attention. With certain exceptions, such as cracks for instance, less emphasis should be placed on the repair of individual defects and more placed on frequency and manner in which radiography is used. Radiography's greatest value lies in control of weld quality.

Some codes call for one spot radiograph of every 50 ft of welding. While this is perhaps entirely adequate for an inspection record, we find erectors using their own spot X-ray equipment will often take more frequent tests. For example, they find it desirable to check the automatic welder at the start of each new seam in order to make any adjustments necessary to produce a sound weld. Also on hand-welded vertical seams more frequent spot X-rays are taken to better control weld quality. Speaking of the problems of controlling weld quality we should bear in mind that every phase of weld fabrication is loaded with the human element especially on field-erected vessels. This is one important reason why qualifications of individual welders is not enough to insure quality welding on a job. One of the functions of radiography is to determine the type of defects and their cause in order that proper action may be taken.

Proper interpretation of radiographs is extremely important. This, however, is not the problem it was five or more years ago. Since World War II the use of radiography for weld inspection has increased to such an extent that the average field welding crew, as well as the inspectors, are entirely familiar with the process. Owners and erectors alike do a great deal of work toward educating their field personnel in the proper use of radiography and radiographic inspection. This, of course, is a very important step in the successful use of the new spot radiographic procedure.

The owners and fabricators have a mutual advantage in building a structure with a minimum of repairs and cutouts.

Extremely portable X-ray equipment easily operated by the welding crew and not requiring darkroom processing is necessary if we are to economically and successfully replace trepanning or sectioning with a true nondestructive test. This then is our "New Concept in Spot X-Ray of Welded Structures." It provides the welding crews with eyes with which to see their work. It provides the owner an economical and better inspection of the product. Our experience during the first year of its use indicates that still further economies of the radiographic procedure will be made. At the present time its use has been confined to petroleum industry and atomic energy work. The favorable acceptance it has been meeting in the field indicates its use will rapidly spread to other industries. We believe this new concept of spot radiography offers industry better welded structures at no more cost and eventually at less cost.

Spot Welding Aluminum with Single Phase Equipment

A schedule has been developed for spot welding four widely used aluminum alloys in 257 different combinations with only eight closely related welding machine settings

by J. W. Kehoe and D. R. McCutcheon

Abstract

A spot welding schedule has been developed whereby the widely used aluminum alloys of 3SH14, 52SH34, 61ST6 and 24ST3 in thicknesses of 0.032, 0.064, 0.091, and 0.125 are spot welded to each similar and dissimilar alloy and thickness on single phase, 60 cycle frequency equipment. This is possible with standard up and down slope controls, with and without dual welding forces. The importance of low inertia force systems for use on work which is to be welded to Military Specification Standards is brought out. On commercial applications, no special force systems are required. The welding machine should have a good operating force system and when used with the schedules shown on Table 1, very high quality and consistent spot welds can be obtained with single weld forces.

Many illustrations prove the difficulty in obtaining quality welds without up and down slope controls, using single and dual (forge) forces despite high tensile shear strengths. This opened up an investigation into low inertia force systems, single and dual forces, and up and down slope controls which further developed engineering design information including minimum overlaps, spot spacings and edge distances, as well as electrode combinations and welding schedules for production use.

This investigation also uncovered dissimilar alloy and thickness combinations wherein the weld nugget formation *between* the materials could not be discerned, yet high tensile-shear strengths are obtained.

Very high quality spot welds which will meet any present Commercial or Military Specification can be obtained with single phase equipment if the welding schedules shown on Table 1 are followed. These welds are obtained with recommended currents that are lower than any hitherto-printed schedule for single-phase equipment.

INTRODUCTION

THE use of aluminum within the Westinghouse Electric Corp. and industry has been increasing quite rapidly during the past three years. A large amount of the increase involves the use of the various welding processes including the inert arc and resistances processes. A considerable volume is being used to replace copper such as in conductor applications as bus bars, transformer windings of both power and arc welding designs. New applications are using aluminum such as in air-borne control apparatus, in refrigerators where copper and copper alloy parts are being replaced with aluminum. The trend is definitely upward so that more applications will find their way into fabricating sections requiring the application of reliable and economic metals joining processes.

There are many reasons to justify the increased use of aluminum in our Westinghouse products. These may be summarized briefly as follows:

1. Economics—Volume by weight is considerably more than copper or steel, and hence lower freight charges per pound of material.
2. Its light weight is desirable on aircraft apparatus.
3. Its competitive cost.
4. Its non-magnetic properties.
5. Its good weldability, particularly with the inert arc process using consumable and non-consumable electrodes.

Since our usage volume is on a definite fast increase, we started a development project early in 1953 to obtain some real basic spotwelding data on the four most widely used alloys in thickness ranges between 0.032 and 0.125 on 3SH14, 52SH34, 61ST6 and 24ST3 alloys. The resistance spotwelding process, being the fastest of any known joining process and the one most frequently used for high production, was the logical place to start.

There are some very important considerations to be evaluated concerning the spotweldability of any aluminum alloys, and these are briefly itemized:

I. Its ability to be spotwelded and what schedule is required to spotweld it to itself or to dissimilar aluminum alloys.

II. Cleaning requirements and means of measure-

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Fig. 1 0.091-in. aluminum sheet—type 52SH34

ment of evaluation of the quality of the cleaning operation.

III. Available equipment—both in the 50 production divisions and in our Headquarters Manufacturing Engineering Welding Laboratory.

IV. Required Quality Standard—Commercial or Military.

V. Welding results and how they could be consistently maintained.

VI. Determination of minimum overlap and spot spacing dimensions. This is a very important requirement because of application requirements for light weight which have to be balanced against the requirement of high welding currents because of the fairly high conductivity, and hence low resistance of aluminum.

VII. Means of measuring and maintaining current records, primarily for Military Standards.

PART I—PRELIMINARY SPOT WELDING SCHEDULES

The first phase of our investigation therefore involved obtaining a welding schedule that would be checked out on the various types of standard equipment, including press, projection-press and rocker-arm types. This was quickly obtained from the wide experience gained in our own development activities in our Headquarters Manufacturing Engineering Welding Laboratory. Strangely enough, there were very few published schedules that could be considered reliable prior to those released by the AMERICAN WELDING SOCIETY in June 1953, and most of these are for three phase or stored energy machines.

Our investigation to date has all been done on single phase a-c welders with 60 cycle frequency. This is due to the overwhelming number of single phase machines throughout the entire Corporation, where in over 3000 a-c spotwelders of all types, there is a very minute percentage of three-phase welders in active production use throughout our 100 different plants, including the manufacturing and repair shops. It should not be inferred here that all 3000 machines might be used on aluminum because in this overall total are small bench welders which do not have sufficient current nor force to weld aluminum of almost any commercial thickness application. However, the investigation of single phase equipment has made us aware of some of its shortcomings—some of which (but not all) are eliminated by three-phase equipment. This report will not cover three phase welding, which will be taken up in a separate report after facts and data are obtained.

One very important factor on any spot welding schedule and of course where weight is a factor is the absolute minimum required overlap for any particular thickness combination that would permit consistent quality spotwelds. Without the use of up and down slope current and time controls, extensive investigation was first made to determine the absolute minimum over lap and spot spacing which can be recommended and used on the various alloys of aluminum. For example, with a combination of two pieces of 0.091 thick 52SH34, the following data were used:

Weld current, amp	40,000
Weld force, lb	950
Forge force, lb	1,900
Weld time, cycles	12

Electrodes: Two $^5/_8$ in. diam—2 in. radius; RWMA Class I—Material.

The above schedule was then used on three standard types of single phase machines including:

(*a*) 250 kva—Press welder—bellows airlock.
(*b*) 400 kva—Projection press welder—piston cylinder with leather cups.
(*c*) 400 kva—Rocker arm welder—piston cylinder with plastic cups.

The following series of figures will illustrate what results can be obtained from standard equipment with

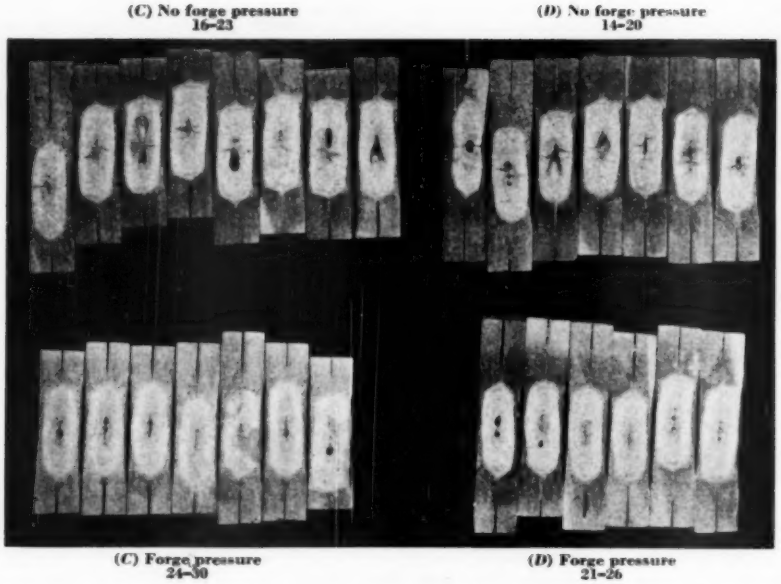


Fig. 2 0.091-in. thick aluminum sheet—type 52SH34

and without forge pressure with a varying width of overlap and spot spacing. The numbers 23–33, etc., represent the number of the welds taken from a series of 50 individual spotwelds.

Figure 1—(*A*) is for $^1/_2$-in. overlap and $^1/_2$-in. spot spacing. Note the severe cracking obtained where no forge pressure is used as can be observed from the upper portion as compared with results obtained with forge pressure as shown in the lower portion of this figure. (*B*) is the same material and welding schedule but with a $^5/_8$-in. overlap and $^5/_8$-in. spot spacing. Notice definite improvement even when using no forge pressure, but with an additional $^1/_8$-in. overlap. Note also the definite improvement when forge pressure is used.

Figure 2—(*C*) indicates the results on the $^3/_4$-in. overlap and $^3/_4$-in. spot spacing while (*D*) indicates results obtained with $^7/_8$-in. overlap and $^7/_8$-in. spot spacing.

Figure 3—This represents results obtained by using 1-in. overlap and 1-in. spot spacing on all three divisions (*E*), (*F*) and (*G*). (*E*) however, used the original 40,000 amp. (*F*) had a reduction of 5% on 38,000 amp. (*G*) had a reduction of 10% or 36,000 amp.

Note the definite reduction in nugget diameters as the current was decreased, and the improvement in the nugget structure when forge pressures are used.

The welds obtained from each of the machines

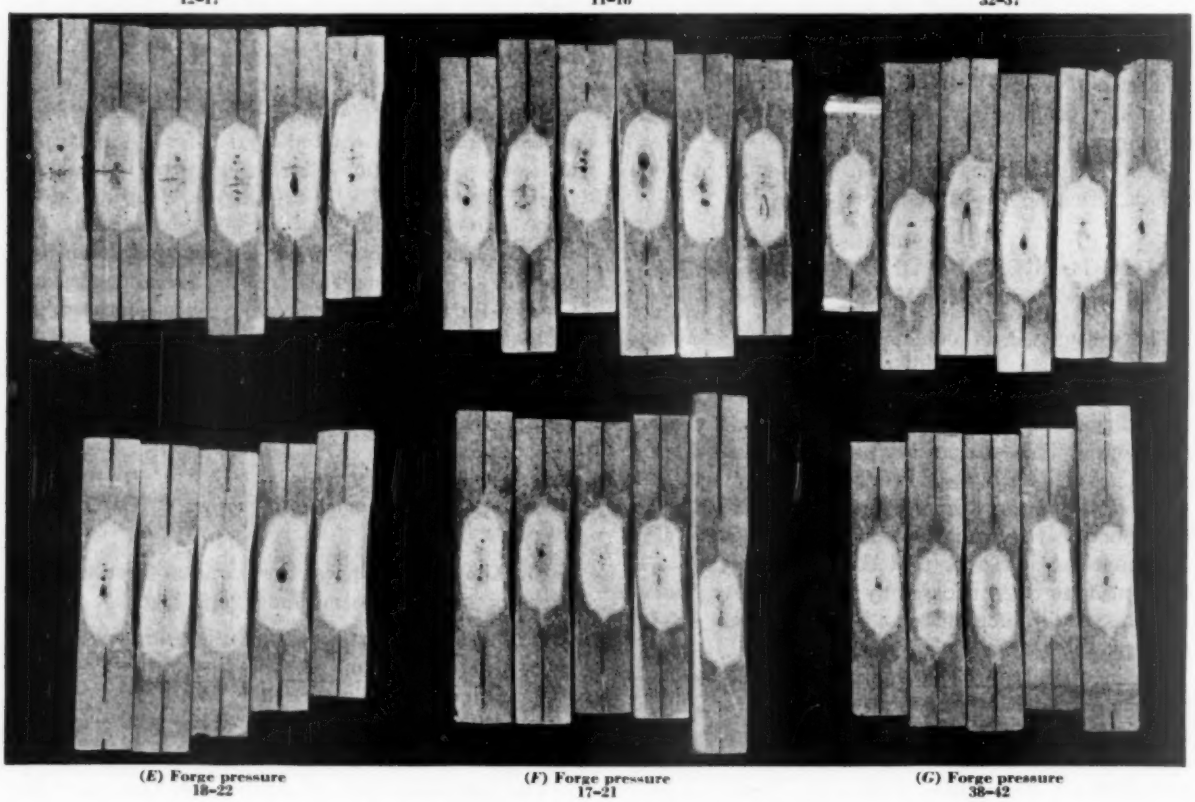


Fig. 3 0.091-in. aluminum sheet—Type 52SH34

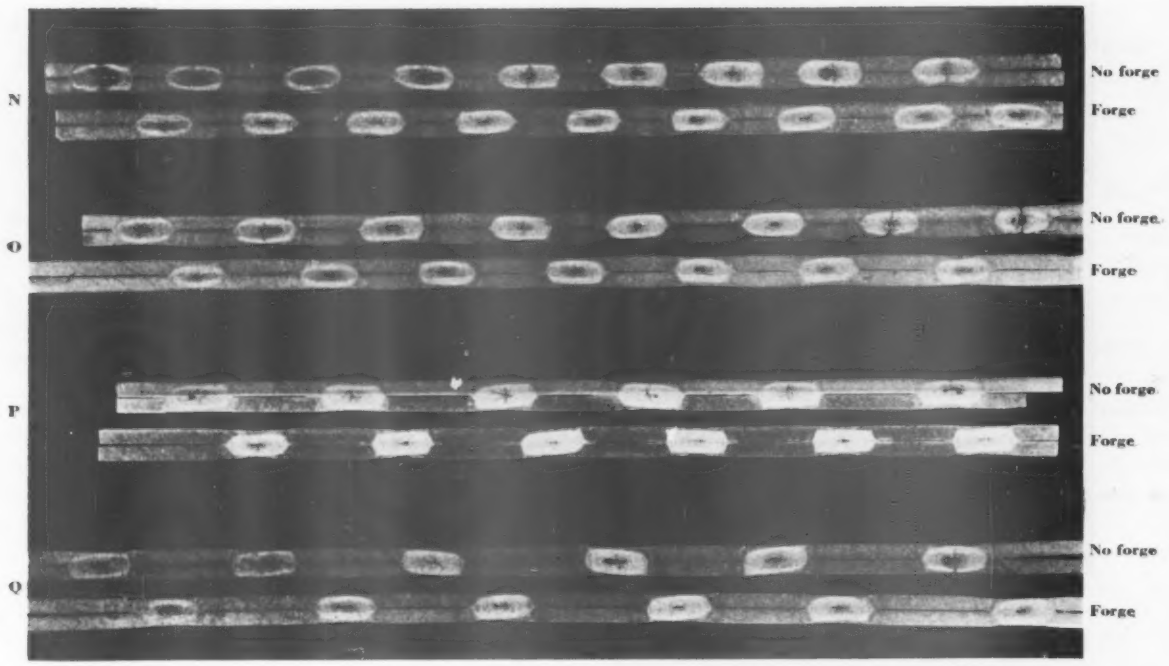


Fig. 4 0.091-in. aluminum sheet—Type 52SH34 Welding force—950 lb. Forge force—1900 lb

varied with the worse results starting with (*a*) machine and improving up to machine (*c*). *None* of the welds would pass any Commercial or Military Standard because of the internal cracks and poor metallurgical quality of the weld nugget. In all cases however, the tensile shear strengths of single spots or multiple spot-welds exceeded Military requirements. This was definite proof that tensile-shear values had little bearing on the nugget quality.

We then proceeded to use dual forces—i.e., weld with one force and apply a higher or forging force to initiate in about the last third of the welding time. This was done only on machines *b* and *c*, as they were equipped with a dual force pressure system. It was found that a definite improvement was obtained when using dual (weld and forge) forces. On the projection press welder, equipped with dual forces but no up and down slope control feature, a series of evaluations were undertaken to endeavor to obtain high quality spot welds that would conform to MIL 6860 requirements. All welds were made on the platens to eliminate the factor of deflection.

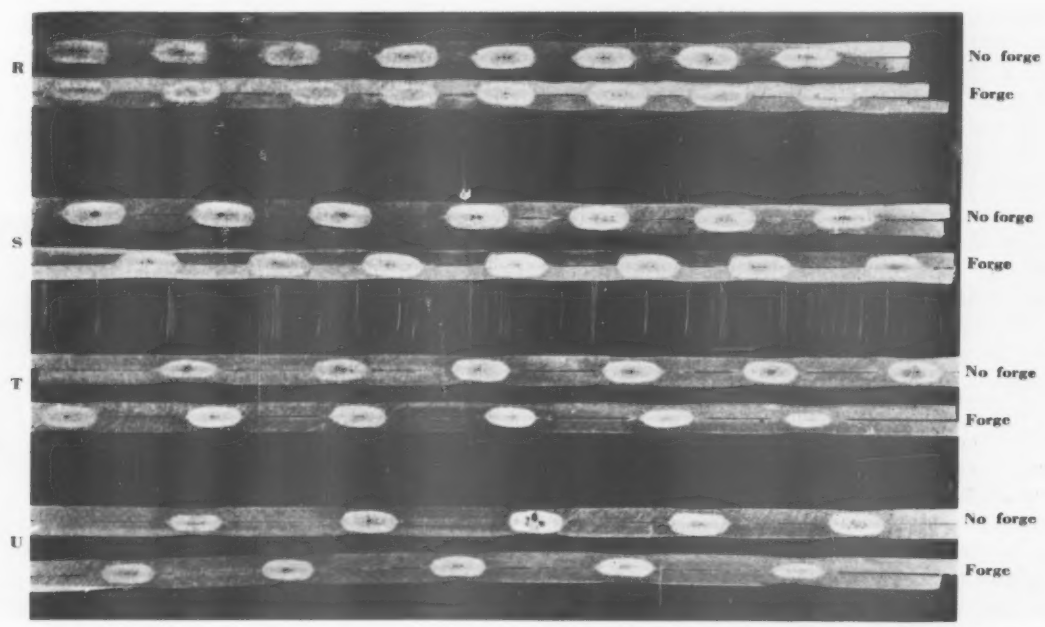


Fig. 5 0.091-in. aluminum sheet—Type 52SH34 Weld force—1500 lb. Forge force—3000 lb

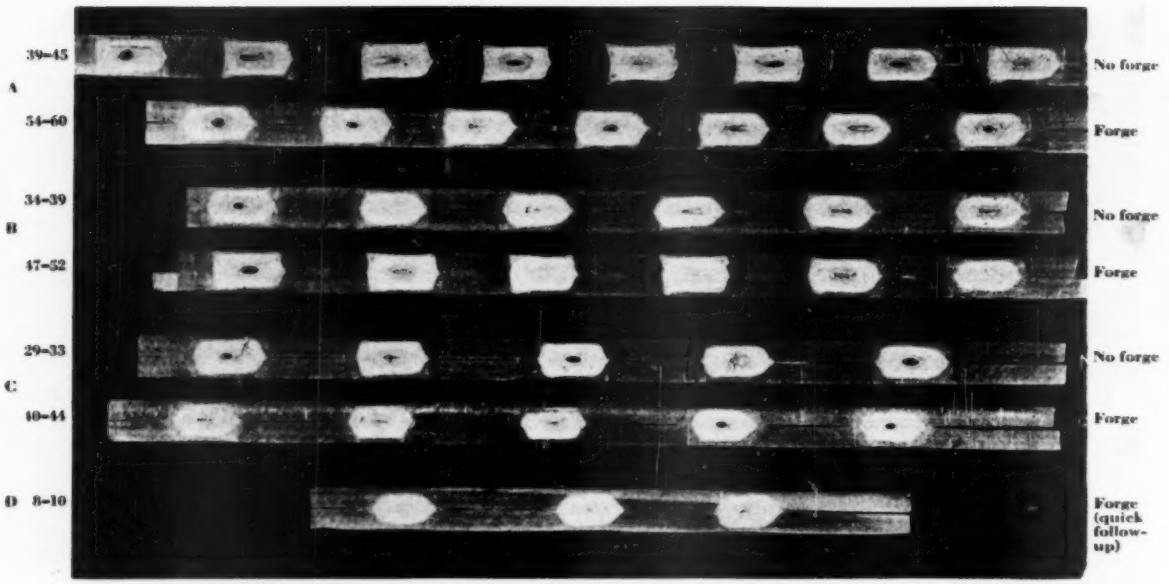


Fig. 6 0.125-In. thick aluminum sheet—Type 52SH34. Weld force 1300 lb. Forge force 2600 lb

Referring to Fig. 4, samples *N*, *O*, *P*, *Q* had these respective spot spacings—$^5/_8$, $^3/_4$, $^7/_8$ and one inch. Note the improvement in weld nugget structure as the spot spacing increased. Note also the definite improvement when forge pressures were used. The weld schedule used was 40,000 amp, 12 cycles with forces as shown on Fig. 4 and two $^7/_8$ in. diam—8-in. spherical radius electrodes.

Figure 5 follows the same spot spacing sequence as Fig. 4, plus the same current and time but with higher dual forces. Note definite improvement in any of the comparative series with the use of higher forces.

From this comparison, an intermediate force of 1200 lb was determined as the single force for this particular thickness combination.

Figure 6 shows two pieces of $^1/_8$ in.—52SH34. Samples *A*, *B* and *C* had respective spot spacings of $^3/_4$, $^7/_8$ and 1 in. These were welded on the same projection welder platens as for Figs. 4 and 5 but with weld currents of 45,000 amp and 15 cycles. Note, too, the same improvement in weld nugget structure with the increase in spot spacing and force.

Sample *D* in this figure was welded on a special rocker arm welder having very quick followup, with the same welding currents, time and forces but with $1^1/_2$ in. spacing. These particular welds would meet MIL Specification requirements without the up and down slope time and current schedule. The special Rocker Arm welder is shown in Fig. 7.

A similar evaluation was made with 3S, 61ST and 24ST materials with similar results all pointing up the need for less critical welding schedules.

Before reviewing the work with up and down slope control schedules, with a determination of minimum overlaps, there is another important consideration, that of cleaning and checking surface resistances, to insure that a consistent low electrical resistance was being obtained and maintained.

PART II—CLEANING AND SURFACE RESISTANCE MEASUREMENT

In order to maintain a few constant conditions, we investigated several commercial cleaning solutions and decided to standardize our cleaning practices by using the caustic etch method which briefly can be described in these two steps:

1. Remove excess oil and grease and inked markings by immersing the parts in thinner or similar grease removing substance; and wipe with a clean dry cloth.
2. Immerse in a 5% aqueous solution of Pennsalt AE 18 or caustic soda for 20 to 40 sec. Maintain the solution between 4.5 and 5.5% (6 to 7 ounces per gallon) and operate at 71–77° C (160–170° F). This

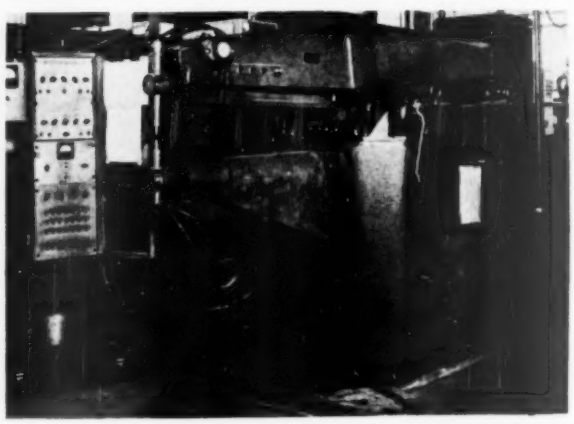


Figure 7

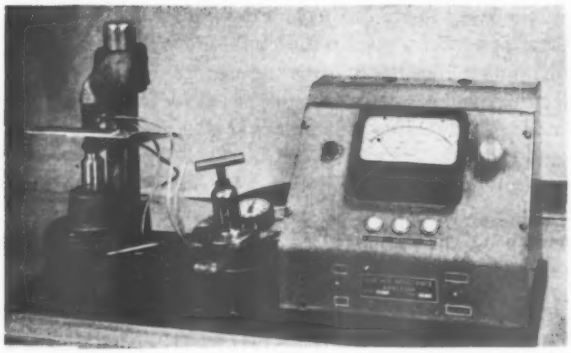


Figure 8

will consistently reduce the surface resistance to less than 50 microhms.

For production cleaning in large and repetitive amounts, the above cleaning method is satisfactory for all four of the alloys herein reported on or use any of the four methods outlined in Table 2 of the 1953 AWS Recommended Practices for Spotwelding Aluminum and Aluminum Alloys.

Throughout the early stages of our study, surface resistances were checked immediately after cleaning and frequently just before welding by several instrumentation devices comprising a force system and resistance measurement. We settled on an inexpensive, portable and accurate Surface Resistance Analyzer which cost $425. This is shown in Fig. 8. A surface resistance of 50 microhms or less was considered as a standard, after some checks indicated this to be a very reasonable value which gave clean welds without any surface expulsion. Tests were conducted on surface resistances between 20 and 200 microhms and it was found that once the period between cleaning and welding was lengthened considerably (3 to 4 days) the surface resistance increased very rapidly from 50 microhms to infinity.

This fact that surface resistance increased rapidly after 3 to 4 days made us interested in several cleaning solutions which used an inhibitor agent in the final rinse that actually stabilized or halted the increase of surface resistance over an indefinite period of 2 to 3 weeks after cleaning. There are quite a few of these on the market today and can be effectively used in cases where storage facilities are available. However where cleaning facilities are in constant use there is little use in storing cleaned parts, as this means extra handling. It is better to clean and weld within 48 hrs than to store cleaned parts indefinitely and then have to recheck surface resistance to be sure conditions have not increased the resistance beyond 50 microhms.

Adopting a standard surface resistance of 50 microhms or less, we then proceeded to investigate a slope and taper adjustment on a Nema type S3UDF control, which was attached to the very latest type of single phase spot welding equipment furnished with two rubber diaphragm air cylinders which tended to buck or boost each other depending on gage and control adjustment, and equipped with a deflection spring microfiring, assuring us of full predetermined pressure before firing. See Fig. 9.

PART III—UP AND DOWN SLOPE CONTROL

Let us review briefly what is meant by an up and down slope control. Some control manufacturers refer to this type of control as follows: (*a*) Up and down slope; (*b*) positive and negative slope; (*c*) rise and taper. NEMA-RWMA have recently established (*a*), up and down slope, as standard.

In keeping with the AWS Committee on Definition recommendations in conjunction with NEMA-RWMA Committee on Electronic and Resistance Welding Control, the term Preheat Current in March 1954 has been defined as follows: "Preheat Current is an impulse of current which flows from the end of the squeeze time

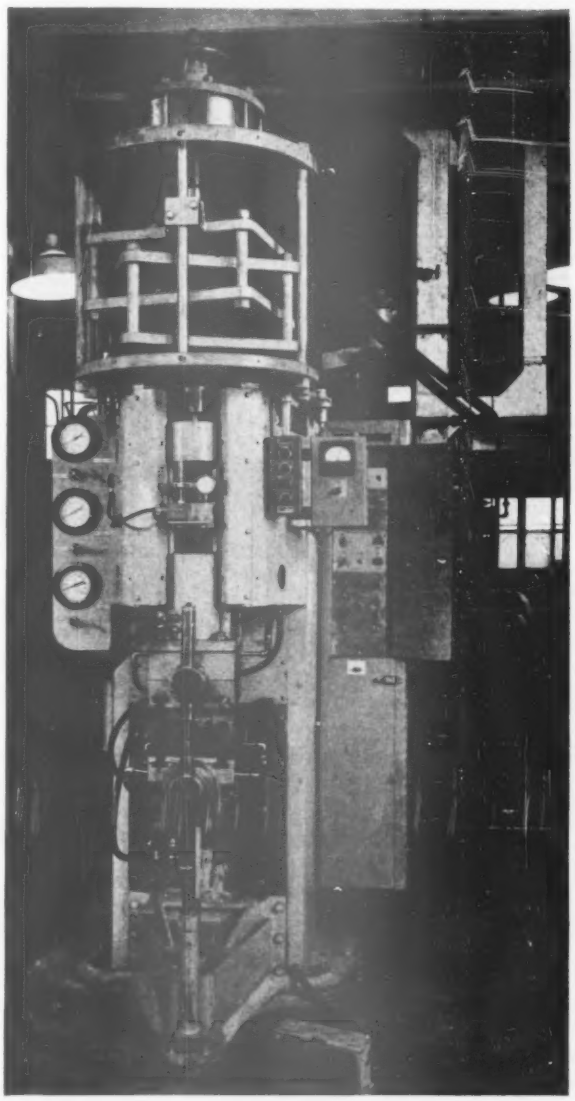


Figure 9

to the beginning of weld time." In order to distinguish between up and down slope controls and preheat, weld and postheat tempering controls that are used on alloy steel spot welding, we use the term "Up Slope Current" for what is commonly referred to as the up slope portion of the heating cycle. The time portion of this Up Slope Current we designate as Up Slope Time. Likewise we wish to use the term "Down Slope Current" and "Down Slope Time" for the tapering functions of this type of control.

Most people are familiar with the conventional sine wave shape of single-phase, 60-cycle currents. The up slope feature enables a smaller current amplitude to initiate, then a gradual building to welding current value—the rate of rise and amplitude of which is adjustable and variable. The exact reverse is true of the down slope circuit. After cessation of weld time, the current gradually decays with the same available adjustments of time and current amplitude. The up slope feature eliminates the customary metal expulsion which occurs when the high welding current starts to pass from the electrodes through the aluminum. The lower and steadily increasing Up Slope Current therefore does three things: (1) permits the electrodes to come into more uniform contact with the material before the higher welding current comes in; (2) permits the use of lower weld forces, which on the soft aluminum material is a real advantage since it means less indentation and therefore more uniform and better appearing weld surfaces; (3) minimizes and practically eliminates the tendency of metal expulsion.

Likewise, the adjustable tapering or Down Slope Current prevents: (1) rapid chilling of the weld nugget and thus refines the grain structure; (2) excessive sheet separation due to sudden release of weld current and force; (3) definitely eliminates cracks and voids in the weld nugget; (4) minimizes the need of forge pressure to insure nugget consolidation. It has been determined in this study that the tapering feature is the most important of the varying current cycle that is used on the rise and taper portions of the welding schedule.

PART IV—DETERMINATION OF MINIMUM UP SLOPE TIME AND CURRENT

To eliminate the tendency of voids or cracks in the weld nugget, it was decided to set the minimum rate of Up Slope on $^1/_8$ in. 24ST3 material (the most critical alloy of the four), since the effect on the heavier material could be more readily examined. For the same current and weld time of 15 cycles, and Up Slope Time was set at increments of 0, 2, 4, 6, 8 and 10. Above 6 cycles and at 0, cracks were detected in the weld nugget, so we arbitrarily selected 4 cycles as the desirable Up Slope Time for any given weld schedule. This was checked repeatedly on every weld schedule developed for the variety of similar and dissimilar thicknesses and found to be consistent.

With 4 cycle Up Slope Time we then set out to establish the lowest value of Up Slope Current. This was found to be 30% of any specific welding current since above this value, metal expulsion was detected, not only

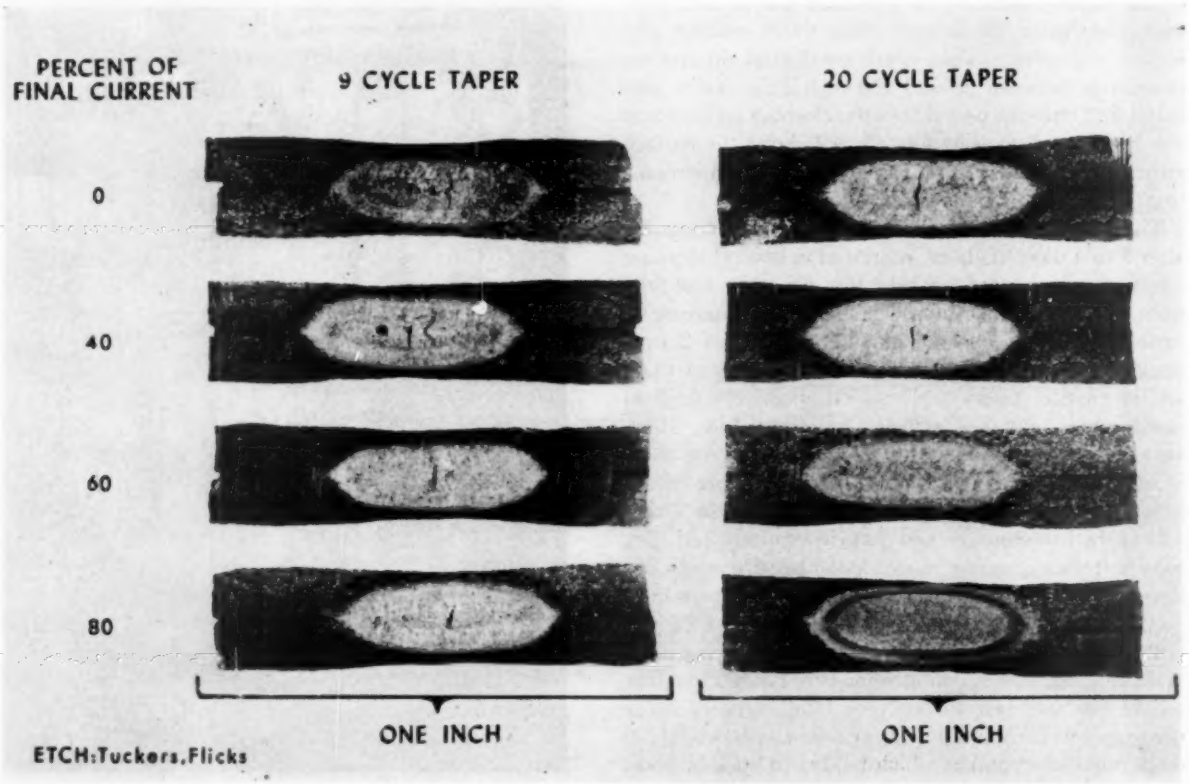


Fig. 10 Effect of final current and taper time on spot welding 24ST3 aluminum. Sheet thickness—0.125 in.

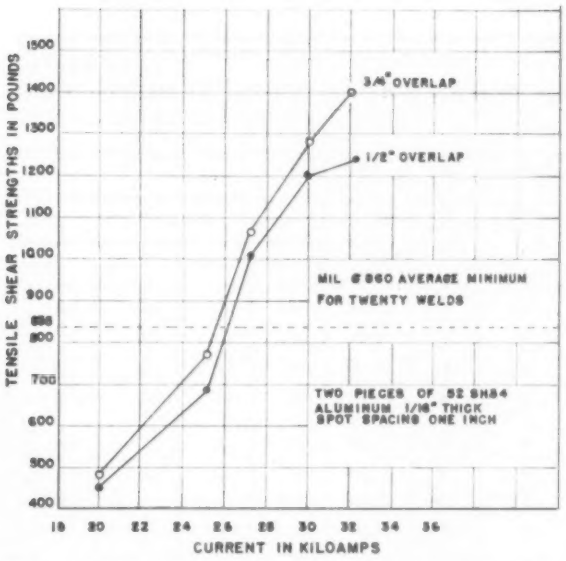


Fig. 11 Weld and shear strength comparison using forge pressures but no up and down slope

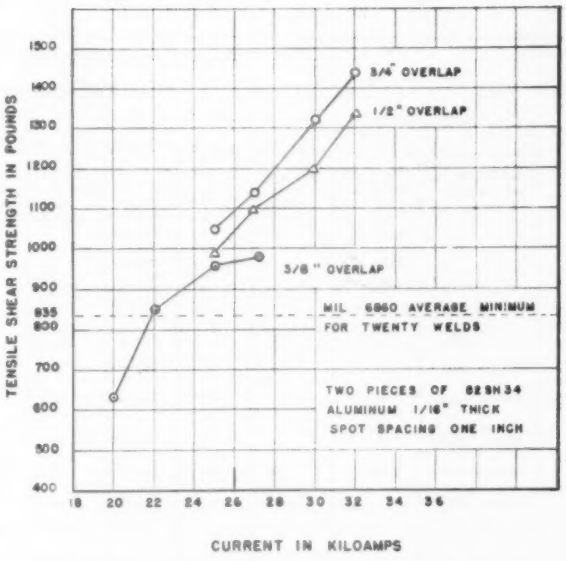


Fig. 12 Weld and shear strength comparison but no forge pressure with up and down slope

visually, but by metallographic examination of weld macros. We therefore settled on Up Slope Currents of 30% of any welding current value and 4 cycles as the up slope time to full welding current. The *30% figure* is accurately determined by measuring the amplitude of the first sine wave of the rising preheat sine wave and comparing this with the welding current; thus the Up Slope Current starts at 30% of the welding current value and builds up to full welding current in 4 cycles.

PART V—DETERMINATION OF DOWN SLOPE TIME AND CURRENT

Disregarding forge pressure, but starting with 4 cycles Up Slope Time and 30% Up Slope Current we proceeded to determine the minimum Down Slope Time and Down Slope Current. The Down Slope Current dial was lowered to zero at the same time increasing the Down Slope Time from 1 to 10 cycles and a high percentage of voids were obtained in the weld nuggets. Then, Down Slope Time ranges were tried from 1 to 9 cycles time and with 100 to 80% current dial settings and voids were still obtained. Nine cycle Down Slope Time was then held constant and the Down Slope Current Dial changed in 10% increments from 80% to 0 and voids were still present although to a lessening degree.

It was then decided to check weld nuggets from 1 to 30 cycles Down Slope Time and from 100% dial setting and voids still were present. Down Slope Time was then set at 20 cycles and the Down Slope Current values changed in 10% increments to zero, and it was found that at 80% current dial setting, no voids or cracks were remaining in the nugget structure. It was also determined that the 80% dial setting was actually 60% of the welding current by measuring the current amplitude wave of the Down Slope circuit.

The results are vividly illustrated in Fig. 10. Summarizing this test:

Material	*Down Slope time, cycles*	*Down Slope current/ (dial setting)*	*Remarks*
1/8—24ST3	1 to 10	100 to 0	Voids
1/8—24ST3	1 to 9	100 to 80%	Voids
1/8—24ST3	9	80% to 0	Slight voids
1/8—24ST3	1 to 30	100 to 0	Slight voids
1/8—24ST3	20	100 to 0	Good at 80%
1/8—24ST3	20	80	No voids

Thus we established for all 1/8 in. thicknesses, an Up Slope Time of 4 cycles with a 30% Up Slope Current, a welding time of 15 cycles, and a Down Slope Time of 20 cycles with 60% Down Slope Current. This same procedure was followed on the thinner gages and also on the dissimilar thicknesses and material combinations and recommended values are shown for all combinations on Table 1.

PART VI—DETERMINATION OF MINIMUM OVERLAP

One of the Westinghouse divisions doing production welding and meeting MIL 6860 process specification requirements with single phase 60 cycle equipment requested positive proof for the absolute minimum overlap distance to settle a long difference of opinion between the engineering and manufacturing departments on this point. The material and thickness combination studied was 52SH34 aluminum and two pieces of one-sixteenths (1/16). A very detailed study was made of this application, which was extended to all materials and thickness combinations as shown in Table 1.

We have found that when high single weld forces are used (no forge), *with* and *without up and down slope*,

TABLE 1

Recommended Single Phase Resistance Spot Welding Schedules for Similar

WELDING DATA													
Thickness Combination (Inches)	Electrode Combination Note A - See Below	Welding Force (Pounds) Note B	Up Slope Time (Cycles) Note C	Up Slope Preheat Current Amperes (30% of Weld Current Note D	Weld Heat Time (Cycles) Note E	Weld Current (Amperes) Note F	Cycles of Weld before Down Slope Time (Up Slope plus Weld Time) Note G	Down Slope Postheat Time (Cycles) Note H	Final Down Slope Current Amperes (60% of Weld Current) Note I	Tensile-Shear Strengths (Lb) Note J — 52SH34 - To			
										52SH34	61ST6	24ST3	38H14
.032 to .032	1	500	4	7,500	8	25,000	12	10	15,000	400	400	450	320
.032 to .064	1	600	4	8,500	10	28,000	14	12	17,000	650	675	650	550
.032 to .091	3 or 6	750	4	10,000	12	33,000	16	16	20,000	1050	925	950	600
.032 to .125	6	1,000	4	11,500	12	38,000	16	16	23,000	1450	1150	1300	1050
.064 to .032	1	600	4	8,500	10	28,000	14	12	17,000	650	675	650	550
.064 to .064	1 or 4	750	4	10,000	12	33,000	16	16	20,000	1125	1050	1175	1000 (NM)
.064 to .091	6	1,000	4	11,500	12	38,000	16	16	23,000	1450 (4)	1450 (4)	1650 (5)	1400 (6)
.064 to .125	6	1,200	4	12,000	12	40,000	16	18	24,000	1850	1650	1750 (5)	1700
.091 to .032	2 or 5	750	4	10,000	12	33,000	16	16	20,000	1050	925	950	600
.091 to .064	5	1,000	4	11,500	12	38,000	16	16	23,000	1450	1700	1650	1250 (6)
.091 to .091	4	1,200	4	12,000	12	40,000	16	18	24,000	1800	2000	1800 (5)	1400 (6)
.091 to .125	6	1,600	4	13,500	14	45,000	18	18	27,000	2000	2150	2700	1770
.125 to .032	5	1,000	4	11,500	12	38,000	16	16	23,000	1450	1150	1300	1050
.125 to .064	5	1,200	4	12,000	12	40,000	16	18	24,000	1850	1850	1750	1350 (6)
.125 to .091	5	1,600	4	13,500	14	45,000	18	18	27,000	2000	2400	2200 (NM)	1445 (6)
.125 to .125	4	2,000	4	15,000	15	50,000	19	20	30,000	2250	1900	3500	2000 (NM)
.125 24ST3 to .125 24ST3	4	3,000	4	16,500	15	55,000	19	20	33,000				

A. Electrode Combination:
1. Two 5/8" Dia. -3" Spherical Radius face
2. One 5/8" Dia. -3" Spherical Radius face
   One 5/8" Dia. - Flat
3. One 5/8" Dia. - Flat
   One 5/8" Dia. - 3" Spherical Radius face
4. Two 7/8" Dia. - 8" Spherical Radius face
5. One 7/8" Dia. - 8" Spherical Radius face
   One 7/8" Dia. - Flat
6. One 7/8" Dia. - Flat
   One 7/8" Dia. - 8" Spherical Radius face

NOTE: Electrode Material - RWMA Class 1.

EXPLANATORY NOTES PERTAINING TO COLUMN HEADINGS ON TABLE 1

A. For various electrode combinations, see lower left corner of Table 1.

B. Welding Force is the net electrode force measured in pounds exerted on the materials being welded.

C. Up Slope Time is the total time for the Up Slope Current to rise from 30% of the Weld Current to full value of the Weld Current. This is 4 cycles for all thickness combinations between 0.032 and 0.125 as shown.

D. Up Slope Current is the impulse of current which flows from the end of squeeze time to the beginning of weld time.

E. Weld Heat Time is the time of duration which Welding Current flows through the materials being welded.

F. Welding Current is the secondary current during the actual welding cycle.

G. Cycles of Weld before Down Slope. This is the dial setting calibrated in cycles and is the sum of the up slope time plus the Weld Heat time cycles.

H. Down Slope Time. This is the total Time during which postheat or taper current flows.

I. Down Slope Current. This is the impulse of current which flows from the end of the weld time cycle tapering down to 60% of the Weld Current.

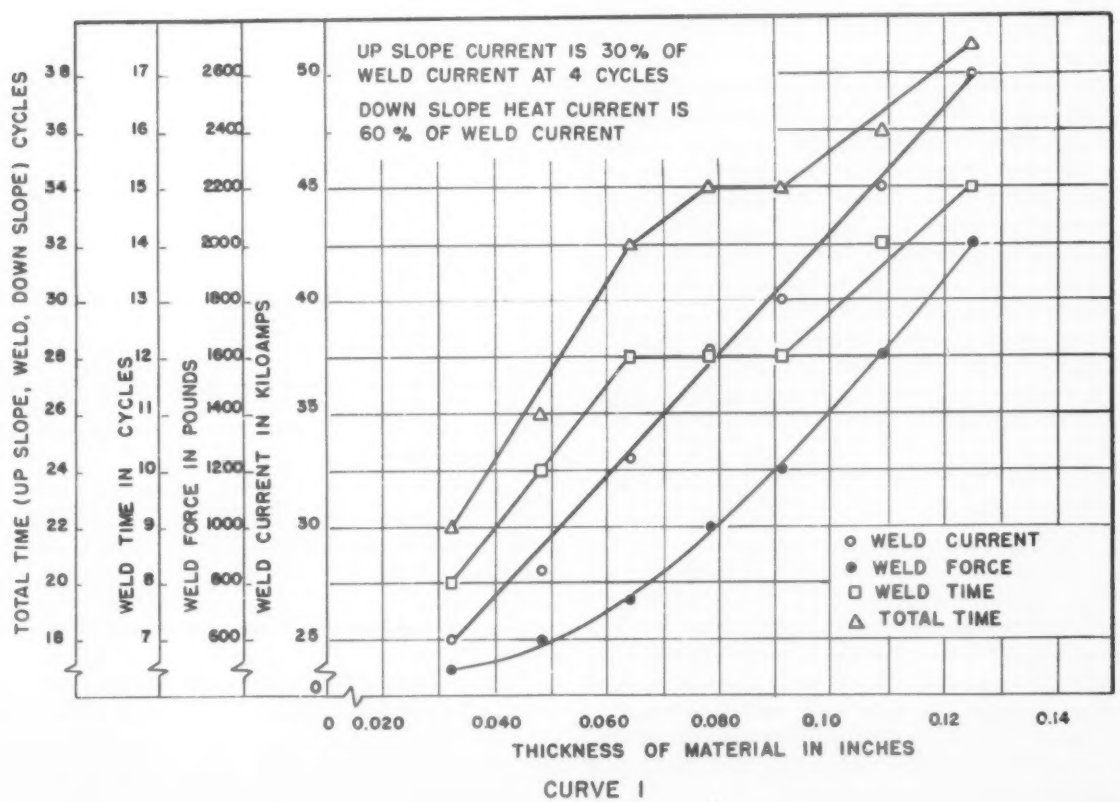
J. Tensile-Shear Strengths are obtained by pulling the overlapped spot-weld joints to destruction in a standard testing machine with the specimens unconfined. These particular shear strengths are obtained with specimen widths equal to Recommended Spot Spacings. The above strengths are the average of 100 multi-spot welds. The number in a parenthesis adjacent to strength values indicates the electrode combination required. See electrode combination reference. For example the combination of 0.064 61ST6 to 0.091 24ST3 shows a tensile shear designation of 1550 (5). By this is meant this combination has a tensile-shear strength of 1550 lb. Also, referring to electrode combination reference for 5, it can be said that a 7/8 in. D—8 in. Spherical radius face electrode is used against the 0.064 thickness of 61ST6 and a 7/8 in. diam flat electrode is used against the 0.091 24ST3 material. Similarly, with 0.064 52SH34 welded to 0.091 38H14 material, the electrode combination is (6). Thus, a 7/8 in. diam flat electrode is used against the 0.064 52S material and a 7/8 in. diam 8-in. spherical radius face electrode is used against the 0.091 3S material.

The designation (NM) adjacent to strength values indicates that this particular combination is Not a Military quality combination. I.e., the minimum weld nugget penetration required in MIL 6860 cannot be met with these schedules.

GENERAL NOTE: Minimum Squeeze and Hold Time should be 15 cycles.

and Dissimilar Aluminum Alloys and Thickness Using Single Weld Forces

INSPECTION AND ENGINEERING DATA															
AVERAGE TENSILE SHEAR STRENGTHS Note J												RECOMMENDED MINIMUM			Thickness Combination (Inches)
61ST6 - To				3SH14 - To				24ST3 - To				Edge Distance	Overlap	Spot Spacing	
61ST6	24ST3	3SH14	52SH34	3SH14	52SH34	61ST6	24ST3	24ST3	3SH14	52SH34	61ST6				
400	400	310	400	300	320	310	300	400	300	450	400	1/4	1/2	3/4	.032 to .032
650	650	525	675	550	550	525	625 (NH)	700	625 (NH)	650	650	1/4	1/2	3/4	.032 to .063
1050	900	600	925	850	600	575	675 (NH)	1150	675 (NH)	700	700	5/16	5/8	1	.032 to .091
1450	1100	800	1150	1085	1050	800	725	1600	725	725	725	5/16	5/8	1	.032 to .125
650	650	525	675	550	550	525	625 (NH)	700	625 (NH)	650	650	1/4	1/2	3/4	.063 to .032
1050	1100	900	1050	750	1050 (NH)	900	850 (NH)	1150	870 (NH)	1175	1100	5/16	5/8	1	.063 to .063
1450 (4)	1550 (5)	1450	1700	1085	1250 (5)	1900 (5)	1150 (NH)	1600	1350 (NH)	1650	1550	3/8	3/4	1	.063 to .091
1850	1675	1550 (NH)	1850	1200	1350 (5)(NH)	1300 (5)	1200 (NH)	1950	1450	1750	1800	3/8	3/4	1	.063 to .125
1050	900	600	925	850	600	575	675	1150	675 (NH)	700	700	5/16	5/8	1	.091 to .032
1450	1550	1100 (6)	1700	1050	1400	1400	1350	1600	1150 (NH)	1650 (6)	1550 (6)	3/8	3/4	1	.091 to .064
1650	1825 (5)	1550 (6)	2050	1100	1500 (5)	1550 (5)	1300	2000	1290 (NH)	1800 (6)	1825 (6)	1/2	1	1	.091 to .091
1700	2400	1650	2400	1250	1450 (5)	1425 (5)	1650 (NH)	2250	1450 (NH)	2190 (NH)	2090 (5)	1/2	1	1	.091 to .125
1450	1100	800	1150	1050	1050	800	725	1600	725	725	725	5/16	5/8	1	.125 to .032
1650	1800	1275 (6)	1650	1200	1700	1550	1450	1950	1200 (NH)	1750 (6)	1675 (6)	5/16	5/8	1	.125 to .064
1700 (6)	2100 (6)	1425 (6)	2150	1250 (6)	1750 (6)	1650 (6)	1500 (NH)	2250	1635 (NH)	2750	2400	1/2	1	1	.125 to .091
2250	2600	1600 (6)	1900	1500	2000 (NH)	1600 (5)	1800 (NH)		1800 (NH)	3550	2600	5/8	1-1/4	1-1/2	.125 to .125
								3000				5/8	1-1/4	1-1/2	.0125 ST3 to .0125 ST3


UP SLOPE CURRENT IS 30% OF WELD CURRENT AT 4 CYCLES
DOWN SLOPE HEAT CURRENT IS 60 % OF WELD CURRENT
TOTAL TIME (UP SLOPE, WELD, DOWN SLOPE) CYCLES
WELD TIME IN CYCLES
WELD FORCE IN POUNDS
WELD CURRENT IN KILOAMPS
WELD CURRENT
WELD FORCE
WELD TIME
TOTAL TIME
THICKNESS OF MATERIAL IN INCHES

CURVE I

that the allowable current variation is very narrow or critical and has to be held within ±5%. The current variation is much less critical when using up and down slope with forge pressures. This is quite reasonable, since the chief function of the forge pressure is to hasten solidification of the weld nugget. This allowable current variation has been found to be ±10% of the recommended value for welding currents shown in Table 1.

Taking the required welding data for these particular overlaps we obtained certain average strengths and compared these strengths and quality of nugget, insofar as voids, cracks and consistency are concerned, and came up with a standard which meets MIL 6860 requirements. A series of tests using overlaps of 3/4, 5/8, 1/2 and 3/8 inch were made and the welding currents varied to determine the resultant tensile shear strengths. We repeated this same procedure and varied the welding technique insofar as up and down slope current values are concerned.

We wish to summarize our findings as follows, referring to the attached charts:

1. From Fig. 11 the variation of strengths with overlaps with a change in welding current can be seen. It is apparent that the reduction in strengths is very rapid when the recommended weld current is reduced below 25% of that value. This is true regardless of other changes in the welding schedule including force, weld time, and over a wide range of up and down slope current adjustments. Note the decided drop off in weld strengths when the weld current falls below 25,000 amp where 33,000 amp is the recommended value.

Another factor explaining this is the fact that the aluminum material having a high conductivity and hence low internal resistance has a narrow welding range and the variables of current, force, time and electrode combinations have to be maintained much closer than those used in spot welding mild steel. Forge pressures were used to obtain the results shown in Fig. 11. Without forge pressures excessive voids and cracks are obtained which would never pass MIL inspection quality and requirements in regards to permissible defects of this type.

The welding schedule used for maximum strengths as shown in Fig. 11 are:

Two pieces 0.063	52SH34 aluminum alloy
Welding current, amp	33,000
Welding force, lb	750
Forge, lb	1,500
Weld time, cycles	12

The current was decreased in 10% increments.

From Fig. 12 can be seen the reduction in strengths for the given overlaps with a revised up and down slope welding schedule. We have been somewhat surprised with the tensile-shear strength consistencies of the results using 3/8 in. and 1/2 in. overlap with the revised up and down slope welding schedule.

2. In the series of welds made with Up Slope and Down Slope Current adjustment, it was found that no forge pressures were required—and the results obtained, in so far as voids and cracks in the weld nugget are concerned, were of identical quality with those shown in Fig. 11, which used forge pressure. This was investigated because of the importance and need of wider overlaps where forge pressures are used.

The optimum welding schedules used for the series of welds shown on Fig. 12, starting with 3/4-in. overlap are:

Welding current and time: 33,000 amp, 12 cycles
Up Slope current and time: 10,000 amp, 4 cycles
Down Slope current and time: 20,000 amp, 16 cycles
Weld force: 750 lb
Total weld time (sum of up slope, weld and down slope times): 32 cycles

3. From visual observation it can be seen that when using a 3/8 to 1/2-in. overlap there is a resultant pushout adjacent to the area of the welding nugget, which is highly undesirable and which might readily be rejected by Military inspection. We recommend a 5/8-in. overlap for the 0.064 thickness combination as the minimum overlap combination, and leave it optional as to whether or not to use forge pressure.

The Importance of Dual Forces

A thorough study of single and dual forces indicated a slight improvement in consistency of weld strengths and in macro quality including a lesser degree of voids and cracks in favor of dual forces where a forging force is applied during the last one-third of the welding time cycle. Use of forging forces also enabled the recommended down slope times and current to be cut in half. However on the other hand, the recommended overlap and spot spacing distances have to be increased from 25–30% greater than those required and recommended for single forces.

Let us compare this directly as shown below for two pieces of 52SH34—1/16 in. thick.

	Using dual or forge forces	*Using single force*
Up Slope Time and current and weld current	Same as shown in Table 1	
Weld time	12 cycles	12 cycles
Electrode force	750–1500 lb	750 lb
Down Slope Current	30% of weld current	60% of weld current
Down Slope Time	8	16
Overlap	5/8 in.	5/8 in.
Spot spacing	1 in.	3/4 in.

NOTE: The forge time is applied after 8 cycles of weld time or the forge delay time dial on the control set on 12 cycles (4 cycle rise + 8 cycle of weld time).

Taking another example from Table 1, two pieces of 24ST3, 1/8 in. thickness.

	Using dual or forge forces	*Using single force*
Up Slope Time and Current and weld current	Same as shown on Table 1	
Weld time	15 cycles	15 cycles
Electrode force	3000-5500 lb	3000 lb
Down Slope Current	30% of weld current	60% of weld current
Down Slope Time	10	20
Overlap	$1^1/_4$ in.	$1^1/_4$ in.
Spot spacing	$1^1/_2$ in.	$1^1/_2$ in.

NOTE: The forge time is applied after 10 cycles of weld time or the forge delay time dial on the control is set on 14 cycles (4 cycles rise + 10 cycles of weld time).

When forge pressures are used, there is more surface area in contact between the electrode and the material, and thus the current density is decreased. This explains why a larger spot spacing is required for forge pressure. Similarly because of the higher contact pressure when using forge forces, there is a tendency to split the material if the electrode is too close to the edge of the material, hence the greater required overlap distances for forge forces.

Thus, for an absolute minimum recommended overlap using forge force, the overlap must be equal or larger than the tip diameter whereas on single or lower forces slightly less or minimum overlap could be used. However it is highly recommended to use the recommended overlap as a minimum for all practical purposes. Having two recommended overlap distances could be confusing and might create a condition where a smaller overlap using single force would be used on applications where dual forces are used.

Larger or wider overlap distances than those shown on Table 1 for the various combinations illustrated will give the production or manufacturing people more leeway and make the operation less critical since the operator can judge his electrode contact more accurately if the electrode does not ride or parallel one edge of a thickness being welded. Table shows recommended *minimum* overlaps.

There are certain fundamentals of spot welding of aluminum which should be kept in mind in a program of evaluating for minimum overlap distances. To begin with, for any given thickness combination aluminum alloys require approximately three times the amount of current as for mild steel of the same thickness combination. Any electrode is limited by its current carrying capacity in amperes per square inch. In the case of applications requiring very small overlaps the electrodes are usually cut down to fit within the dimensions of the overlap distance. Once this is done the life of the electrode is immediately limited because of a very high current density, which is a result of the reduction in the conducting area. Another limitation to a spot welding electrode will be the amount of force exerted on the welding end; as the electrode contact surface is *reduced* so too is the force of pressure psi. *increased*. The result is that a very undesirable condition is obtained whereby very close control of the tip contour, shape and cooling temperature

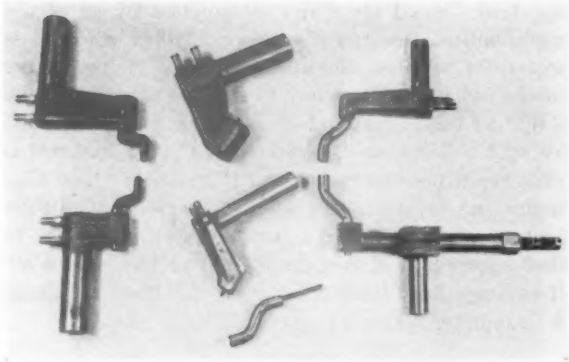


Figure 13

is required. Furthermore, the use of forge pressures requires adequate overlap distances and in the case of offset tips, the higher forge forces are a limiting factor because the offset tip face is smaller to begin with than standard straight full diameter electrodes. The combination of offset holders and electrodes as shown in Fig. 13 should be avoided by proper engineering design that will eliminate their need or use.

PART VII—DETERMINATION OF MINIMUM SPOT SPACING

Once the minimum overlap distance is determined, it was comparatively easy to determine the minimum space between spot welds. A strip of 25 welds were run with various spot spacing distances, but we decided to try to have the minimum spacing as nearly equal to the overlap distance as possible and this actually worked out fairly close as planned. When a strip of 25 welds were made, each spot made in succession was numbered and the sheets were cut apart on centers exactly between each pair of spot welds. The average deviation of each individual tensile-shear specimen was set at 10%, and once we exceeded a definite distance between spots, this consistency was easily maintained. This particular minimum distance became the minimum spot spacing and it is slightly greater, 25 to 30%, than the overlap distance for the individual thicknesses, and fortunately all four aluminum alloys came out identically. This was checked on all combinations shown in Table 1.

PART VIII—ELECTRODES

Electrodes of $^5/_8$-in. diam can be used on thicknesses up to two pieces 0.064 aluminum. Above that, up to and including two thicknesses of 0.125, a $^7/_8$-in. diam electrode is recommended. On thicknesses between 0.064 and 0.125, an 8-in. spherical radius, $^7/_8$-in. diam electrode has been found to give the best results based on indentation limitations of Military Process Specification 6860. Below 0.064 thicknesses, a 3-in. spherical radius face is used. The electrode material in all cases is RWMA Class I with the water hole drilled to within $^1/_2$ in. of the contact surface. In other words, these are

standard Class I electrodes as supplied by all of the representative electrode suppliers. This material is better for welding aluminum, because it has higher conductivity, less tendency to stick to aluminum than RWMA Class II material which is widely recommended for spot welding steel, and besides Class I material is 12% less expensive than Class II material. The electrodes are cleaned during welding operations and their contour maintained by a paddle-type tool similar to that referred to in Section 405 (*d*) of the 1953 AWS Recommended Practices for Spot Welding Aluminum & Aluminum Alloys.

PART IX—CURRENT MEASUREMENT AND RECORDS

With the use of different current values for up slope, weld and down slope currents, the pointer stop ammeter cannot be used precisely to set all three current values. It is used only to aid in setting up the maximum value of current, which is always the welding current. The control dials for up slope and down slope current are set for various percentages of the welding current so this simplifies the use of the meter which is connected to a current transformer exactly as used in the recommended setup for spotwelding mild steel and which can be used as a guide to setting up recommended welding current.

For accurate records of Up Slope, weld and Down Slope currents, a Brush Recorder is required. This is strictly a laboratory type of instrument and the average production operator should not be expected to use this instrument like he can the primary meter. The Brush Recorder makes an accurate visible record of the various current wave shapes and can also be used simultaneously to take force readings, including single and dual forces which vary during the welding cycle. A delicate strain gage is required for force measurements on the brush for determination of initiation of forge pressures. A force gage is used to measure forces for setup purposes.

It is not the purpose of this paper to go into detail of the operation of the brush equipment. For those interested in what equipment is required, there are three units used in single phase a-c measurement and these are obtained from the Brush Development Company, Cleveland, Ohio, along with required strain gages and a Standard Shunt having a resistance of 0.1 or 1.0 ohm for Brush voltage signal pickup.

One dual channel oscillograph—Type BL-202
One a c amplifier—Type BL-905
One universal amplifier—Type BL-320
Total from Brush Development Co.
Strain gages—Types A-1 and A-11
Obtained from Baldwin Locomotive Works Testing Equipment Div., Eddystone, Pa.
One 0.1 ohm Shunt Model 4221-10 amp continuous
From Leeds & Northrup, Philadelphia, Pa.

The Brush equipment costs approximately $1500 for all three pieces included above. The strain gages and shunt cost approximately $100.

No doubt it is obvious that Brush records are a *must* when welding to any Military Specification where hourly checks and visible and physical proofs are required. However, to those who are interested in up and down slope controls, the above Brush equipment should be secured because this is the only precisely accurate means of checking single phase currents and/or forces separately or simultaneously. A current transformer mounted in the primary of the welding transformer is used in conjunction with the meter, hence it is frequently called a primary meter.

PART X—RECOMMENDED SPOT WELDING SCHEDULES—TABLE 1

The eight different schedules shown on Table I for 257 combinations of four of the most widely used aluminum alloys represent the *maximum* heat which will produce a quality standard that will meet any commercial or Military specification standard similar to MIL 6860. We realize that the recommended weld and down slope times for single forces are perhaps longer than one might ordinarily have used in the past, however, the consistent quality obtained from these schedules are without question and have been proved on production work for over the past year and can conform to all requirements of MIL Specification 6860.

Curve I shows weld current and times, weld forces and total heat time plotted as ordinates against thicknesses as abscissa. Thickness gages in between those reported herein can have the required currents and time cycles estimated by reference to this curve. On dissimilar thickness combinations, take the average thickness of the combination by adding the two thicknesses involved and dividing by two and consider the combination based on this average thickness.

But for an honest evaluation of all the facts we have come across material combinations which while they will meet any commercial strength requirement, they will not meet the requirements for nugget penetration of 20–80% as required in Section G-2c and 2d of MIL 6860. These are designated on Table I under the Tensile Strength columns as NM, meaning that they are *Non-Military* quality welds. There were 29 dissimilar material combinations in the 257 combinations shown in Table I. Neither single nor dual (forge) forces were successful with these NM welds.

For example, in Fig. 14, for the combination of 0.063 3SH14 to 0.125 24ST3, note the absence of any nugget penetration in the 3S material yet this combination has a tensile shear strength of 1200 lb. In this same Fig. 14, note the 0.063-3SH14 to 0.125-52SH34 combination, where there is also no nugget penetration in the 3S material and yet this combination had a tensile shear strength of 1350 lb.

Somewhat contradictory, but nevertheless true, in Fig. 15 the thinner 24ST3 to the heavier 3SH14 material is a weldable combination that meets MIL standards. Likewise in Fig. 16, the thinner 52SH34

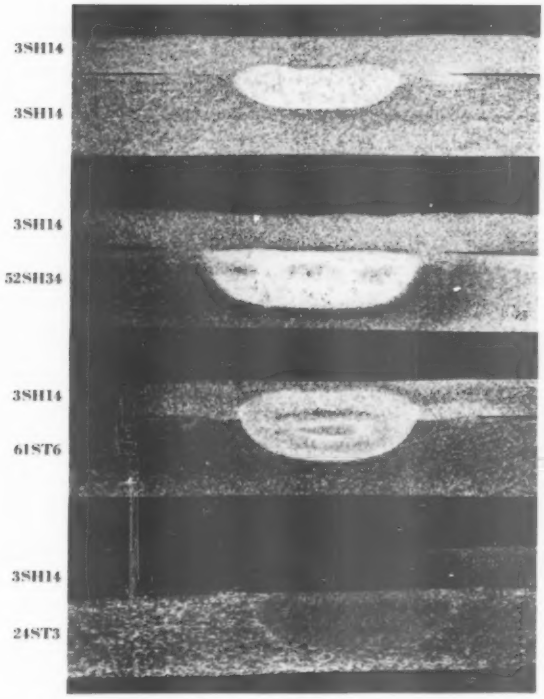


Fig. 14 Macrostructure of aluminum spot welds. Sheet thickness—0.063–0.125 in.

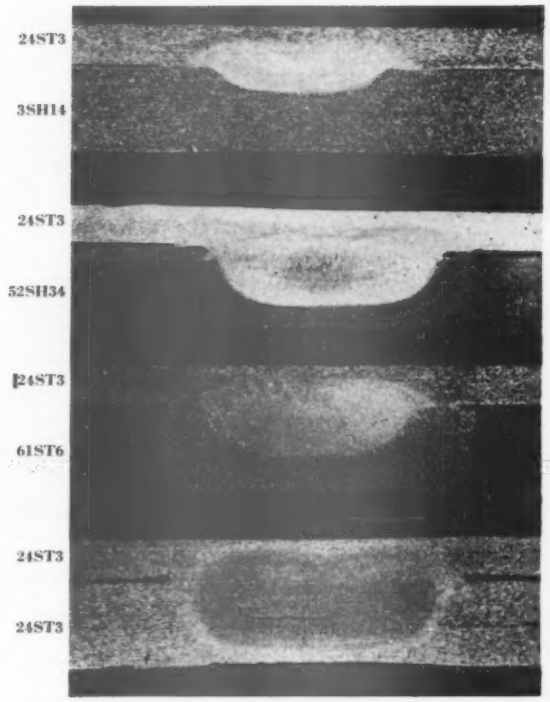


Fig. 15 Macrostructure of aluminum spot welds. Sheet thickness—0.063–0.125 in.

material to the heavier 3S material is a weldable combination that meets MIL standards.

Please note how it has been practically impossible to obtain an equal nugget penetration in both of the materials. Every type of electrode material, including the Elkonite grades (RWMA Class X and XI) were used to try to "pull the nugget" into both materials and this along with a variety of tip designs proved fruitless. Yet in every case, the tensile-shear strengths and the macro-quality of the weld nugget met or exceeded the requirements in MIL 6860 for the same thickness of either of the two separate alloys. MIL 6860 does not

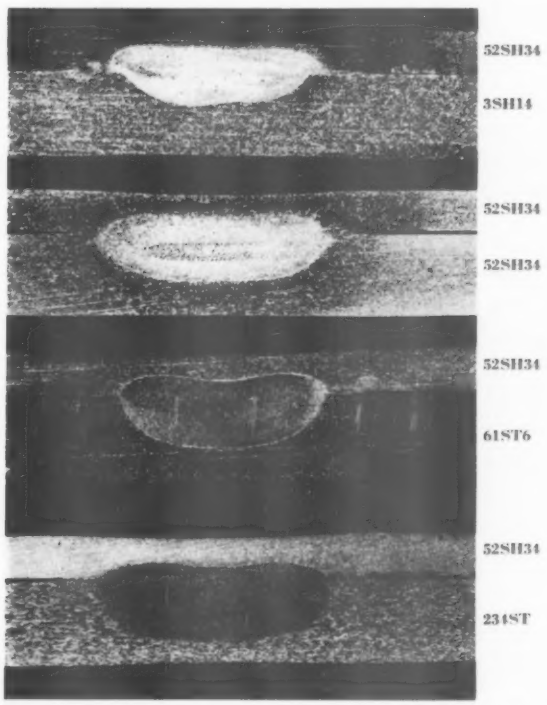


Fig. 16 Macrostructure of aluminum spot welds. Sheet thickness—0.063–0.125 in. Etch: Flick's reagent. Mag. 4×

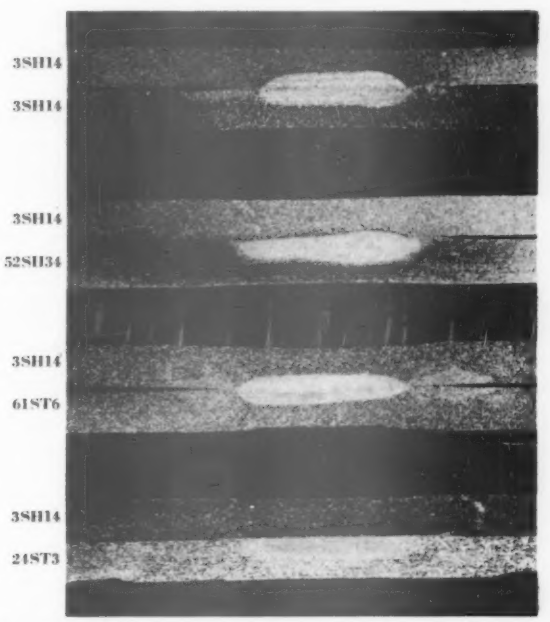


Fig. 17 Macrostructure of aluminum spot welds. Sheet thickness—0.063 in. Etch: Flick's reagent. Mag. 4×

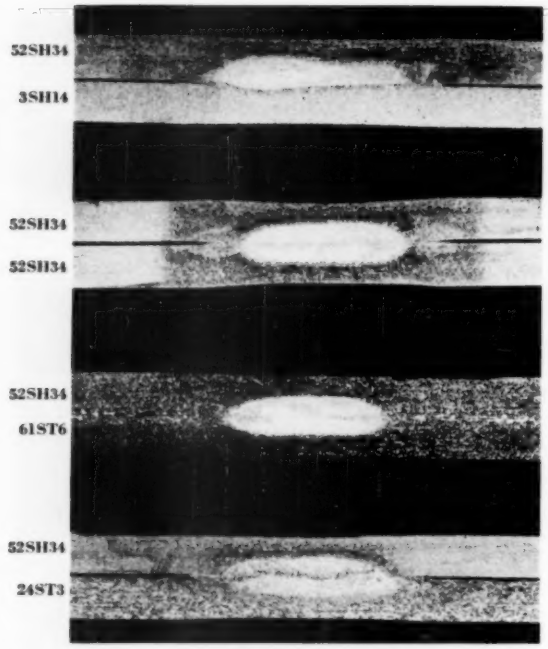


Fig. 18 Macrostructure of aluminum spot welds. Sheet thickness—0.063 in. Etch: Flick's reagent. Mag. 4×

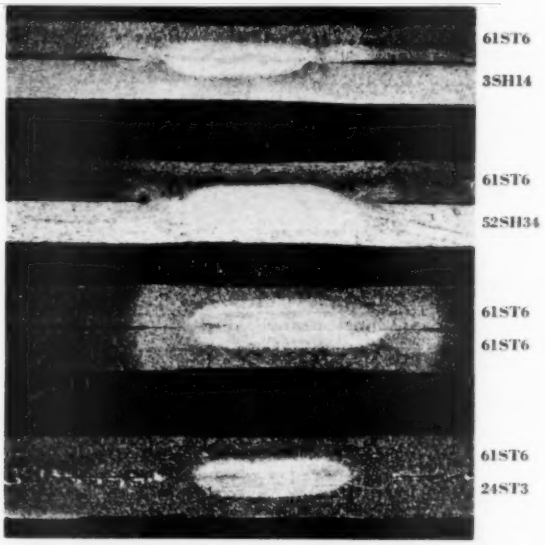


Fig. 19 Macrostructure of aluminum spot welds. Sheet thickness—0.063 in. Etch: Flick's reagent. Mag. 4×

give requirements for dissimilar material combinations. Throughout this entire study we have set our sights on an average of 50% weld nugget penetration in each thickness and material combination being welded.

We have refrained from indicating *nugget diameters* in the developed schedules as shown in Table 1. This is due to the option of using single or dual (forge) forces, where a slightly larger diameter nugget is obtained with a single force and a smaller diameter and smaller-grain structure nugget is obtained with dual (forge) forces.

Reviewing further the results of the 257 combinations covered in Table 1, taking the similar thicknesses of each of the 4 alloys in the similar and dissimilar material combinations, Figs. 17, 18, 19 and 20 illustrate photomacros (4× magnification) of the results obtained with 0.063 thickness similar and dissimilar material combinations.

Figure 17. The combination of 0.063 3SH14 to itself and to 0.063 61ST6 is a good weldable one, but the combination of 0.063 3SH14 to 52SH34 and to 24ST3 while designated as Non-Military quality still have average tensile shear strengths exceeding Military specification requirements for either material welded to itself.

Figure 18. The combination of 0.063 52SH34 to 0.063 3SH14 is a Non-Military quality, one that ex-

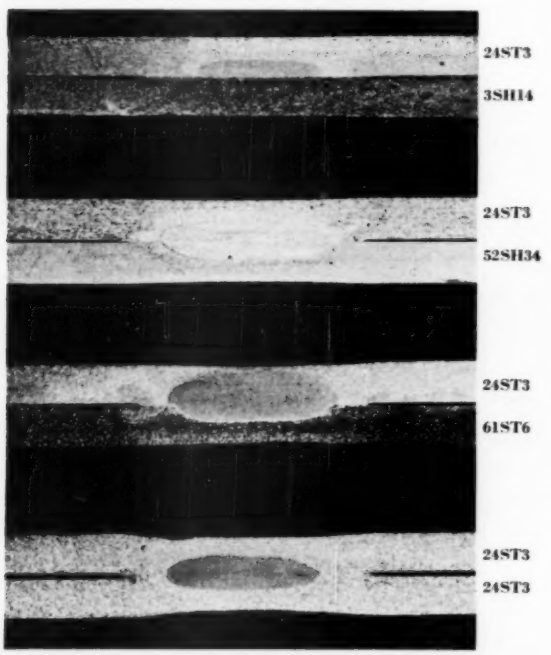


Fig. 20 Macrostructure of aluminum spot welds. Sheet thickness—0.063 in. Etch: Flick's reagent. Mag. 4×

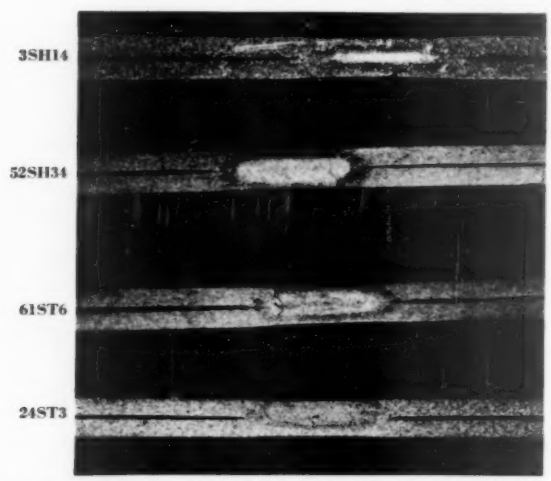


Fig. 21 Macrostructure of aluminum spot welds. Sheet thickness—0.032 in. Etch: Flick's reagent. Mag. 4×

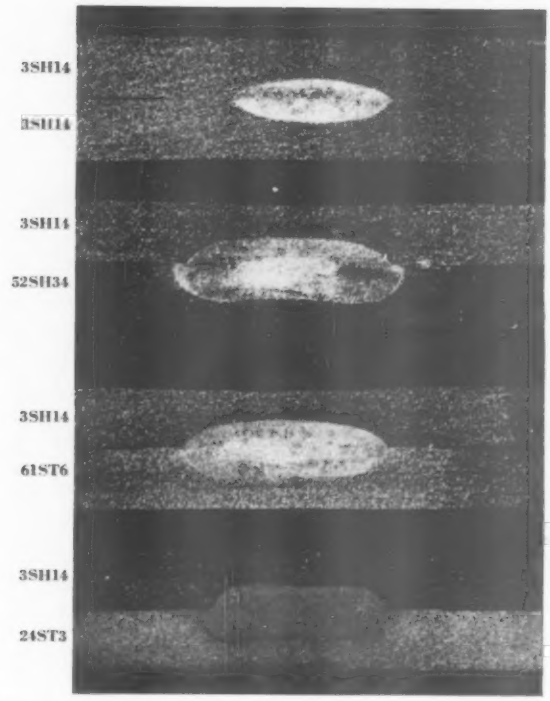


Fig. 22 Macrostructure of aluminum spot welds. Sheet thickness, 0.091 in. Etch: Flick's reagent. Mag. 4×

ceeds Military specification requirements for either material welded to itself. The combinations of 0.063 52SH34 to 0.063 thicknesses of itself, 61ST6 and 24ST3 are all around acceptable quality welded combinations.

Figure 19. The combinations of 0.063 61ST6 to 0.063 thicknesses of itself, 3SH14, 52SH34 and to

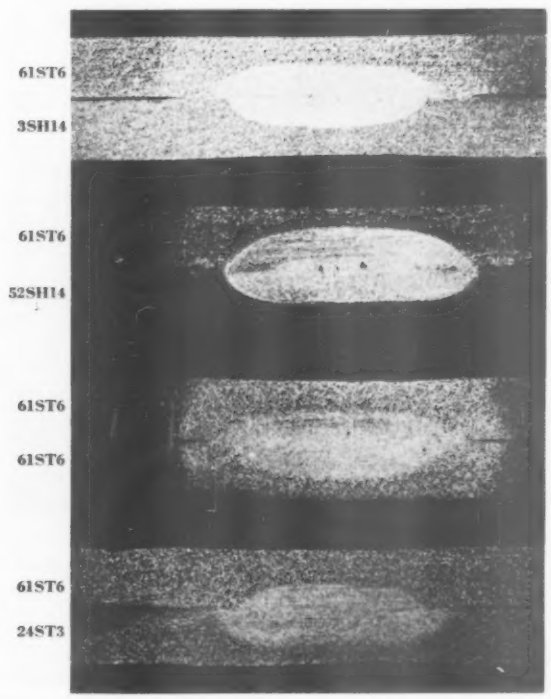


Fig. 24 Macrostructure of aluminum spot welds. Sheet thickness, 0.091 in. Etch: Flick's reagent. Mag. 4×

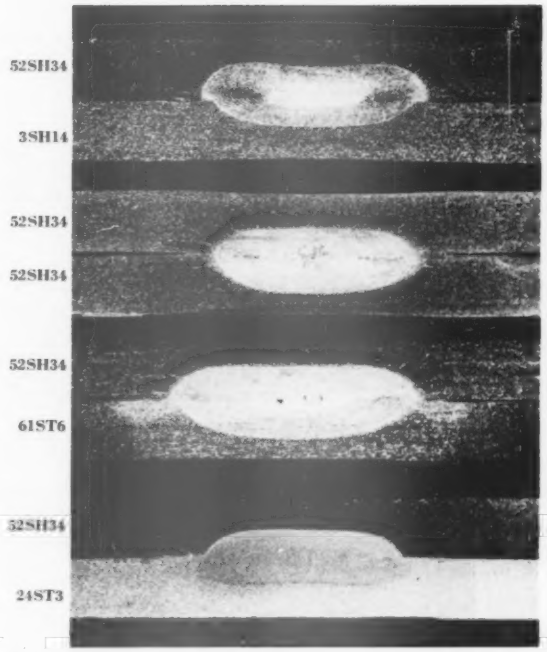


Fig. 23 Macrostructure of aluminum spot welds. Sheet thickness, 0.091 in. Etch: Flick's reagent. Mag. 4×

24ST3 are all around acceptable quality welded combinations.

Figure 20. The combination of 0.063 24ST3 to 0.063 3SH14 has been found to be of non-military quality because of the lack of nugget penetration in the 3SH14 material, yet the tensile-shear strengths of this combination pulled 870 lb which exceeds MIL 6860

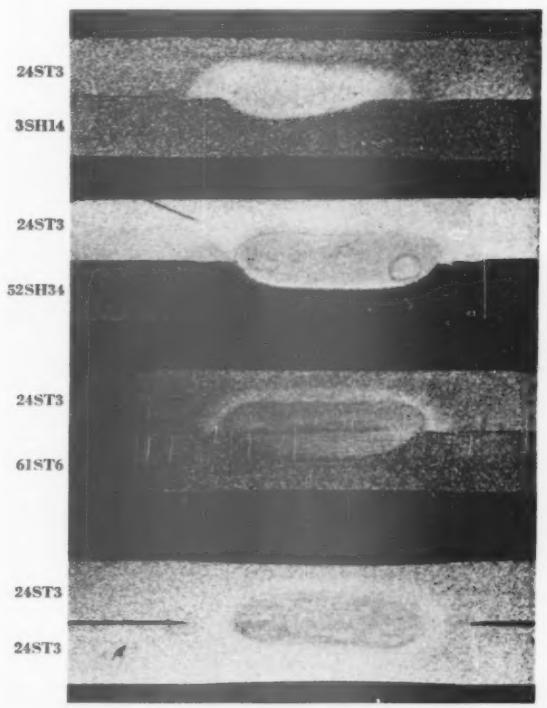


Fig. 25 Macrostructure of aluminum spot welds. Sheet thickness, 0.091 in. Etch: Flick's reagent. Mag. 4×

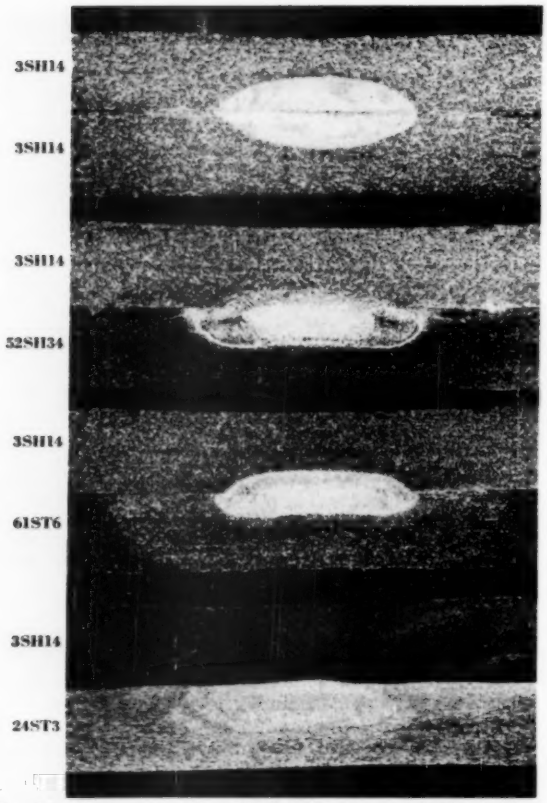


Fig. 26 Macrostructure of aluminum spot welds. Sheet thickness, 0.125 in. Etch: Flick's reagent. Mag. 4×

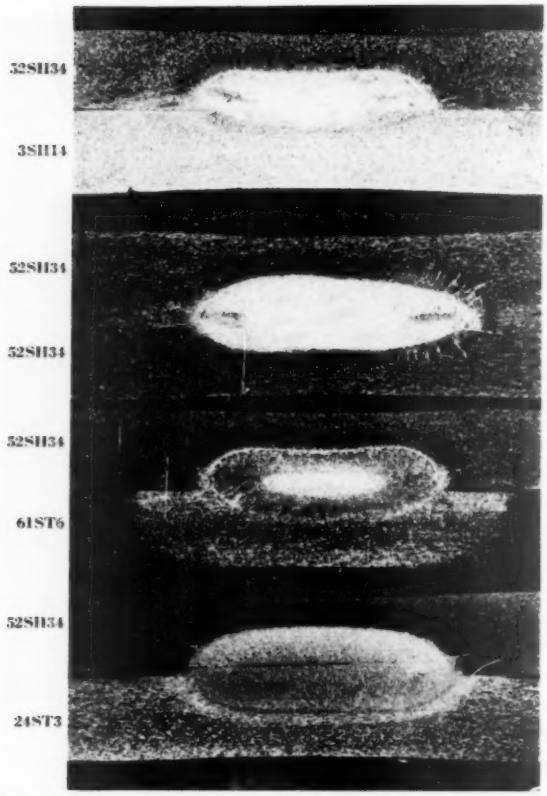


Fig. 27 Macrostructure of aluminum spot welds. Sheet thickness, 0.125 in. Etch: Flick's reagent. Mag. 4×

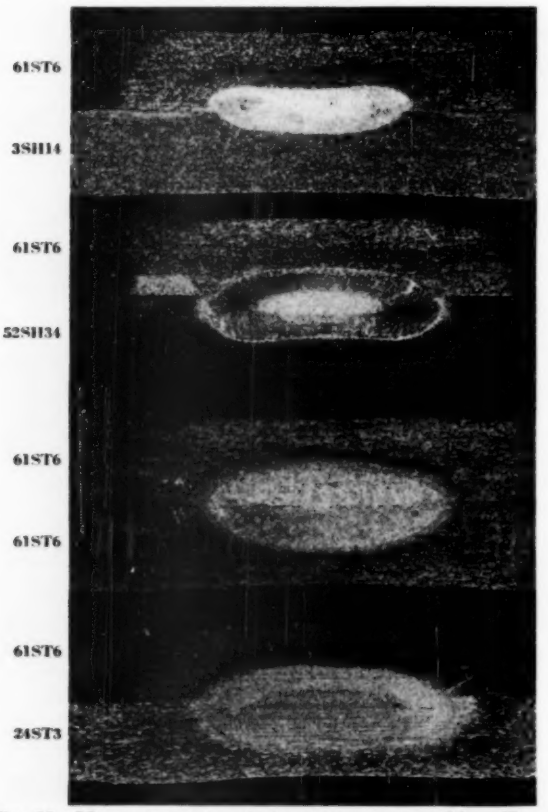


Fig. 28 Macrostructure of aluminum spot welds. Sheet thickness, 0.125 in. Etch: Flick's reagent. Mag. 4×

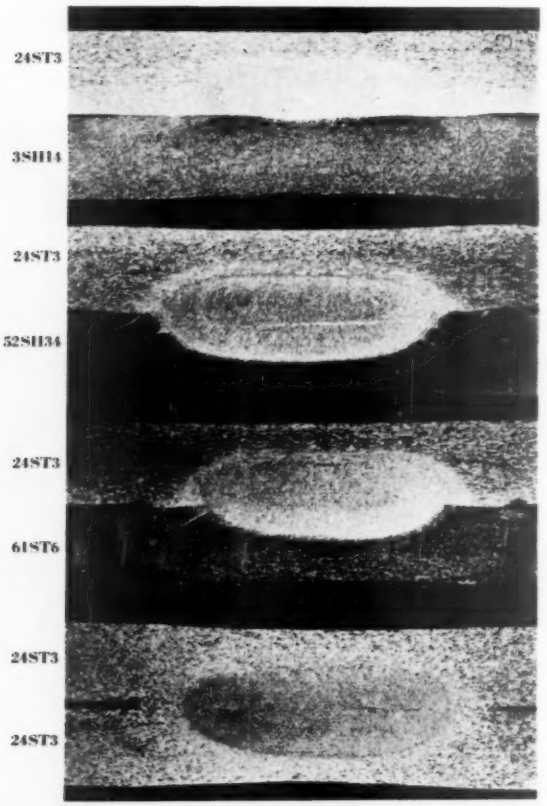


Fig. 29 Macrostructure of aluminum spot welds. Sheet thickness, 0.125 in. Etch: Flick's reagent. Mag. 4×

specification requirements for either material welded to itself.

Figure 21 illustrates the results obtained on the 0.032 combinations of the four alloys to themselves.

Reviewing the 0.093 thickness similar and dissimilar material combinations, Figs. 22, 23, 24 and 25 illustrate the results obtained and recorded on Table 1.

Figure 22. The 0.093 thickness combination of 3SH14 to the other three alloys are quite satisfactory in regards to acceptable weld quality.

Figure 23. As in Fig. 22, the 0.093 thickness combination of 52SH34 to the other three alloys are quite satisfactory in regards to acceptable weld quality.

Figure 24. Likewise the 0.093 thickness combination of 61ST6 to the other three alloys are quite satisfactory in regards to acceptable weld quality.

Figure 25. Likewise the 0.093 thickness combination of 24ST3 to the other three alloys are quite satisfactory in regards to acceptable weld quality.

The 0.125 thickness similar and dissimilar material combinations results are shown in Figs. 26 to 29 inclusive.

Figure 26. The 0.125 thickness combination of 3SH14 to itself and to 61ST6 is of acceptable quality but the 3SH14 to 52SH34 and to 24ST3 are considered as non-military quality even though the welded combination have tensile-shear strengths in excess of what MIL 6860 requires for the materials 52SH34, 24ST3 and 3SH14 welded to the same materials.

Figure 27. The 0.125 thickness combination of 52SH34 welded to 3SH14 has already been shown in Fig. 26 as being an unacceptable weld combination. However 0.125 thick 52SH34 to the other three alloys of the same thickness are of acceptable quality.

Figure 28. The 0.125 thickness combinations of 61ST6 to itself and to all the other three alloys are of acceptable weld quality. It should be evident that 61ST6 is turning out to be the best weldable alloy to the other three dissimilar alloys.

Figure 29. The 0.125 thickness combination of 24ST3 welded to 3SH14 is of unacceptable quality but 24ST3 welded to other 0.125 thicknesses of itself, 52SH34 and 61ST6 are of acceptable weld quality.

Completing the survey of combinations, Fig. 30 illustrates that 0.063 thickness 61ST6 to 0.125 thickness 3SH14 is not of acceptable weld quality, but is satisfactory when welded to itself and to the other two alloys of 0.125 thickness.

A very exacting test of the ductility of the spot welded joint is the cross-bend test which is accomplished by cutting a $^1/_{16}$ in. wide sliver from the center of the spotweld in the direction of the grain and also in the longitudinal section of the slightly-elliptic shaped nugget. This is polished and etched to bring out the nugget structure and the weldment is then bent to a 45 to 90 degree. If no cracking occurs in or on the edge of the weld nugget the weld can be considered quite ductile. Figure 31 illustrates three samples of dissimilar combinations put to this test. A random selection of the good weldable combinations shown in Table 1 responded very favorably to this cross-bend test. However the time and effort required to make this particular test does not warrant its being made a standardized test procedure.

The best practical test for evaluation of the weld obtained is the tensile shear test with portable equipment that is reasonably priced for any commercial standard.

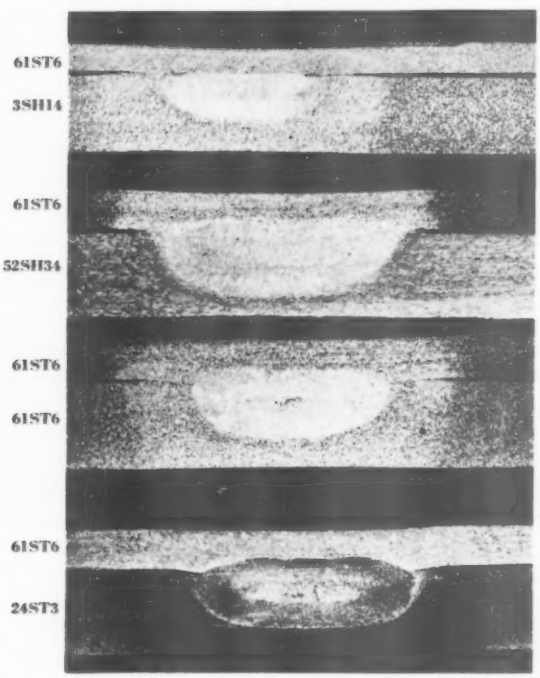


Fig. 30 Macrostructure of aluminum spot welds. Sheet thickness, 0.063–0.125 in. Etch: Flick's reagent. Mag. 4×

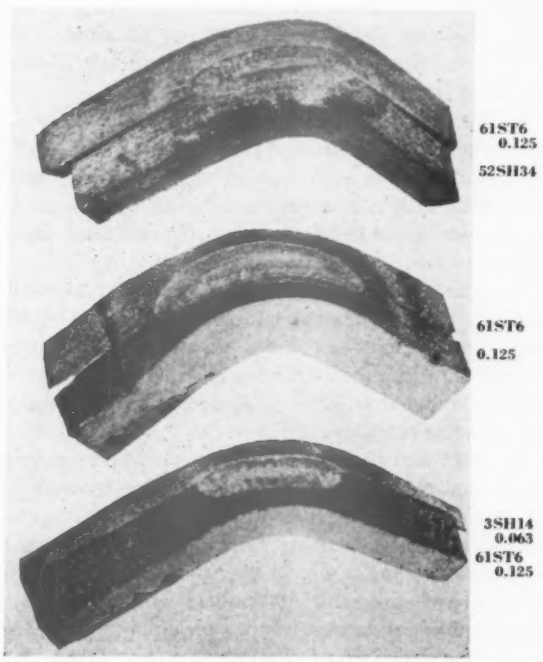


Fig. 31 Cross section Bend test. Mag. 3×

This physical test data plus the required macro-etch test, are a requisite in MIL 6860. However, once it has been determined that the recommended values of up slope, weld, and down slope currents and time cycles are being consistently obtained, the need of testing commercial welds is obviously unnecessary. MIL 6860 has a requirement for hourly tests which can be waived at the discretion of the resident inspector. It has been previously stated that weld current variations ±10% of that recommended will still produce welds that are of acceptable strength and macro-quality, but tip life in the case of higher currents and nugget penetration in the case of lower currents have to be considered so it is desirable to maintain the recommended welding currents which if compared with other printed schedules are lower. Thus the power or kva demand for these schedules is not excessive and in many cases—particularly with the two pieces of 1/8 in. thickness combination is lower than any hitherto printed schedules for single-phase equipment. This low current recommendation plus the relatively long current times and low weld forces bring the required kva ratings of machines down to a more reasonable economic level. Then, too, the longer current times enable a good power supply system to level off or recover from the initial demand which it does in the first quarter of the recommended values in Table 1. This has been checked and verified on voltage oscillograms. In any case the single phase power supply system should maintain voltage regulation within ±7.5% that of its rated supply (220 or 440 v).

PART XI—FORCE SYSTEMS

The schedules shown in Table 1 use forces, both single and dual, lower than hitherto printed schedules for three-phase and in many, but not all, single phase schedules. Here, too, is another advantage of these schedules in that it does two main things:

1. Permits the use of smaller frame machines, because Resistance Welder Manufacturers' Association have standardized their machines into various classes depending on KVA, current and forces. The larger the forces, the larger the frame size required, and thus a higher initial cost.

2. The lower forces recommended in the schedules in Table 1 permit the use of any good air cylinder construction and do not necessitate low inertia and special designs of quick follow-up force systems for Commercial standards and over 80% of Westinghouse applications fall into this category.

To meet and maintain the high consistency requirement that MIL 6860 calls for, we recommend low inertia force systems with dual forces. This, together with the fact that there are 15 or more manufacturers of resistance welding equipment in this country which offer various and different mechanical characteristics in their individual machine types prompts us to recommend low inertia-dual force systems to meet MIL requirements.

What is a low inertia force system? We respectfully submit that the most commonly used principle is that of rubber diaphragm cylinder construction which has different trade names, but the one most commonly known type is that known as Rotochamber. The machine shown in Fig. 9 which we obtained basic data that was later checked on standard machines has two rubber diaphragms—the top one being 18 in. diam and the bottom 12 in. diam. The lower or smaller diaphragm is the bucking cylinder when dual forces are used, so upon electric solenoid initiation the air is exhausted out of this cylinder and the larger cylinder is exerting the forging pressure. The large operating cylinder on the top is a standard air cylinder having leather cups and the function of this cylinder is to operate the head down to within one inch of the work where the rubber diaphragms then take over as their stroke is limited to one inch. This particular machine has a micro-firing attachment which insures *safe initiation* of the weld current once the preset force has been exerted on the work. This is not a requisite but is a very reasonably priced optional feature that provides operator protection and will prevent premature firing as the electrodes begin to exert force on the work. Anyone who has seen or experienced premature firing will readily agree that the micro-firing feature will save its cost in electrodes and ruined work caused by the welding current initiating during the buildup of force with sluggish moving force systems that perhaps are in need of overhauling or replacement.

The force system illustrated in Fig. 9 built up from 300 lb to 5500 in 2 cycles, as indicated from strain-gage measurements. That is certainly low-inertia fast follow-up for an air system of this size! The force range on this machine is 500 to 12,500 lb.

PART XII—ELECTRONIC CONTROLS

While the recommended welding current times are long, it might be first thought that non-synchronous timing controls are satisfactory provided they have phase shift current adjustment on the up slope, welding and down slope current circuits. Improvements in non-synchronous controls have made them highly desirable in many cases on brazing and steel spot welding. From long experience we would recommend fully synchronous controls when spot-welding aluminum. The package control used in this study on the machine in Fig. 9 is identified as Nema S3UDF having spot and pulsation timing along with up slope, welding and down slope current and time, and forge functions. This control is used for a wide range of work, so a Nema SZUDF having spot but no pulsation timing would be perfectly satisfactory for use with the schedules recommended in Table 1.

On some types of synchronous spot timing controls it is possible to add separate circuits for the up and down slope current and time functions, and if the existing controls already have the forge controls, the control additions will enable conformity to the schedules shown

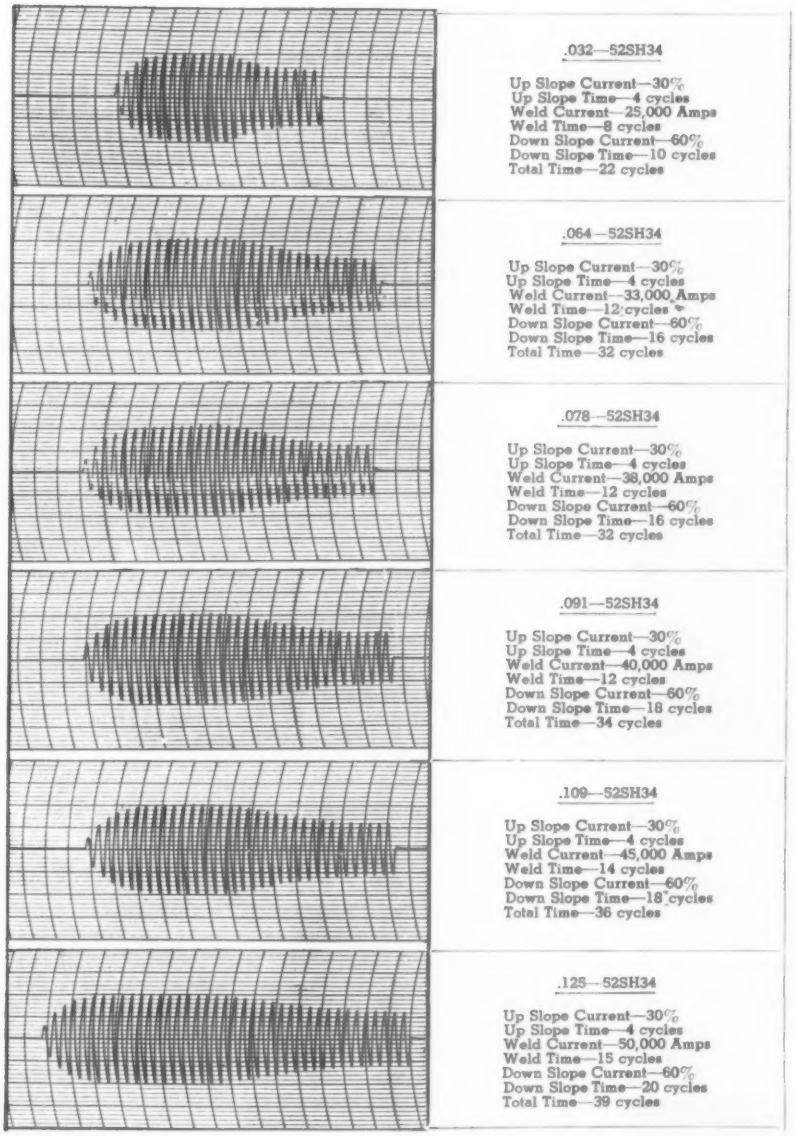


Figure 32

in Table 1, provided the mechanical operation of the pressure system is operating satisfactorily.

Figure 32 illustrates the complete current wave shapes involved in the six different welding schedules covered in the 257 combinations shown in Table 1. You can prove to your own satisfaction our recommendation of up slope and down slope percentages of 30 and 60% respectively in regards to the welding current. For example, the welding current is set at 10 division deflection (measured from the zero part of the line). Note that the up slope amplitude is three divisions or 30% of the welding current and the down slope amplitude is six divisions or 60% of the welding current. This should also make it apparent how to use the pointer stop primary meter as a setup guide to welding current and then use calibrated dial settings for up slope and down slope adjustments or settings.

PART XIII—CONCLUSIONS

1. A welding schedule consisting of eight different machine settings has been developed for resistance spot welding 257 combinations of four widely used Aluminum Alloys in four thickness ranges and combinations from 0.032 to 0.125 in. See Table 1.

2. A series of curves have been assembled from the developed schedules shown in Table 1 to give a quick starting point for dissimilar thickness combinations not shown on Table 1. See Curve I.

3. Recommended Up Slope Currents and time cycles and Down Slope Currents and time cycles have been developed and are included in Table 1.

4. Table 1 is primarily for single forces but can be used with dual forces with recommended values of Down Slope Time and Currents half of those in Table 1.

5. Single weld forces will produce a high quality standard spot weld when used with up and down slope schedules as shown in Table 1 that will meet existing commercial or Military specifications.

6. When spot welding to MIL Specifications, dual (forge) forces and low inertia force systems are recommended with a Nema type S2UDF control.

7. Single phase equipment can be qualified and the schedules shown on Table 1 certified for any Military specification at present in existence.

8. A primary current meter can be used to set up recommended *welding* currents on commercial applications using schedules on Table 1.

9. When welding to a Military Specification such as MIL-W 6860, Brush recording equipment is required for visual records of up and down slope and weld current and time cycles.

10. All similar and dissimilar alloys and thicknesses cannot be welded to meet Military quality standards in so far as nugget penetration is concerned. These combinations are classified as NM in the Average tensile-shear strength columns in Table 1.

11. 61ST6 material is the best material for welding to similar and dissimilar alloys and thicknesses, based on NM rating. Out of 64 combinations only one 61ST6 combination is classified as NM—Non Military quality. In the usual order behind 61ST6 are the following alloys: 52SH34 (with 3 NM combinations); 3SH14 (with 12

NM combinations); and 24ST3 (with 13 NM combinations).

12. Some special electrode combinations are required on dissimilar alloy and thickness combinations and these are shown as the electrode combination in parenthesis adjacent to the respective tensile-shear values. See Note J pertaining to Table 1.

13. No special single phase spot-welding equipment is required to use the schedules shown in Table 1. A good force system, not necessarily low inertia, is required for commercial quality standards. However, low inertia force systems have been adopted as standard equipment by some welding equipment manufacturers.

14. Data has been submitted with proof that sound welds *cannot* be made on the Aluminum Alloys herein covered by the schedules in Table 1 without up and down slope controls on single phase equipment. The addition of a Nema type S2UDF control will improve the results obtained on a machine in good operation considerably and could be the difference permitting certification to a Commercial or Military Specification.

15. The use of up and down slope controls permits the use of lower welding currents and forces and thus lowers the KVA capacity of welding equipment required for single-phase welders.

Equipment References

1. Figure 8—Surface Resistance Analyzer—C. B. Smith Co., Long Beach 8, Calif.
2. Figure 9—400 kva Projection Press Welder—Federal Machine and Welder Co.
3. Portable Tensile-Shear Tester—Model BT—Detroit Testing Co., Detroit, Mich.
4. Force Gage—Catalog 6987801G1—General Electric, Schenectady, N. Y.
5. Rotochamber—Bendix-Westinghouse, Eyria, Ohio, or any RWMA equipment member representative.

Bibliography

NOTE: The first three references are papers given at the Third Conference on Electric Welding in Detroit, 1952, jointly sponsored by AIEE and AWS.

"Slope & Taper Control in Spot Welding 24ST Aluminum," by I. W. Johnson.

"Instruments to Improve the Operation of Single Phase and Three Phase Resistance Welding Machines," by William R. Stern.

"Industry's Answer to MIL-W Specifications. What Fabricators Have Done to Meet These Specifications," by F. L. Brandt.

Recommended Practices for Spot Welding Aluminum and Aluminum Alloys, AMERICAN WELDING SOCIETY, 1953.

"A Practical Method for Obtaining Consistent Resistance Welds," by J. W. Kehoe, THE WELDING JOURNAL, Oct. 1950.

Braze-Welded Furniture Beautifies the Home

by E. J. Chester

MANY home owners have adopted "wrought" iron furniture as an important part of their decorating schemes. One of the accepted methods of fabricating furniture from wrought iron is by braze welding. With braze welding used, the joints are made quickly and easily, and special finishing operations are not usually necessary.

The manufacturer of the cigar stand, being welded in Fig. 1, covers the braze welds with paint during the over-all finishing operation, and has no additional work to do on the welded joints. When the furniture is completed, it will add useful beauty to any room which contains it, and the braze-welded joints will insure a lifetime of sturdiness for each of the pieces.

E. J. Chester is with the Linde Air Products Co., Grand Rapids, Mich.

Fig. 1 With the pieces held in this small jig, the operator is braze welding the legs to the top of a "wrought" iron cigar stand

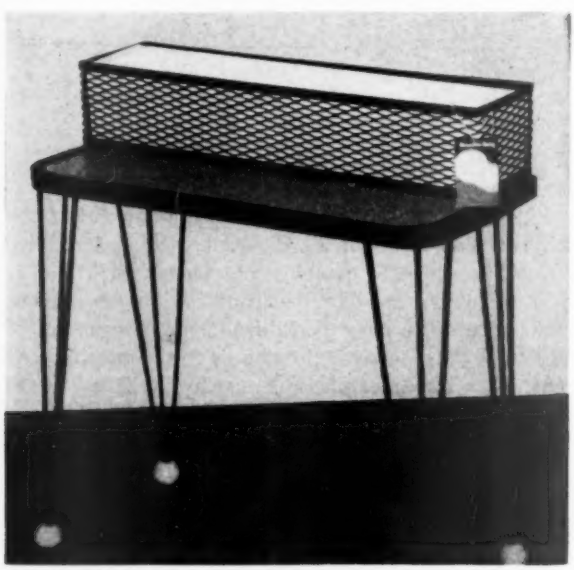


Fig. 2 This "wrought" iron table, with a flower box, will add beauty to any indoor or outdoor decorating scheme

EDITORIAL PREVIEWS

Westinghouse Opens Alabama Electrode Plant

MODERN production techniques, latest quality control methods, good plant layout and a high degree of self-sufficiency characterize the new Westinghouse Electric Corp. plant in Montevallo, Ala., for the manufacture of welding electrodes and brazing rods. This modern single-story plant, located on a 54-acre site 35 miles south of Birmingham, will consume over two million pounds of hot-rolled wire per month in the manufacture of welding electrodes.

Part of the current Westinghouse 296-million-dollar expansion program, the Montevallo plant was built to meet the growing market for electrodes and brazing rods in the South. It is the first electrode plant in the South. Approximately 100 persons will be employed at Montevallo when the plant is at full production with a total annual payroll of about one half million dollars.

Fig. 1 Wire for welding electrodes is drawn to size on this wire-drawing machine. Prior to the drawing operation, the wire has been mechanically descaled. From here it is wound on spiders which are taken to . . .

Fig. 2 Wire cutting machines. These machines straighten and cut the wire to length in one operation. Straightening is done by giving the wire a 60-deg twist about the longitudinal axis. Containers from the machines are shuttled onto the conveyor system where the proper level is automatically selected to take them to . . .

All labor, with the exception of some supervisory personnel, is being hired from the immediate area.

The plant has essentially three lines: one for welding electrodes, an adjacent line for compounding flux coatings and a line for the manufacture of Phos-copper® and Phos-silver® brazing rods. Loading and unloading docks are located near the center of the 402-ft-long plant. The welding electrode line forms a tight oval with part of the facilities overhead. The flux compounding line adjoins the electrode line and consists of weighing and mixing facilities. The brazing rod line, which requires much less space, is located at one end of the plant.

Hot-rolled wire is brought in either by truck or rail and is mechanically descaled by passing it over a series of rolls to give it sharp bends. It is then air hosed before it goes into a wire drawing machine to be drawn to size. Two lines of this type feed a series of wire straightening and cutting machines.

The wire is cut into lengths of 14 and 18 in. It is simultaneously straightened by twisting it about the longitudinal axis. The containers carrying the cut wire are shuttled onto a two-level conveyor where an elevator automatically selects the conveyor level by

Fig. 3 Flux Coating. Electrodes coming off this line must pass a concentricity check of 0.002 in. The control panel in the background will adjust the rate of wire feed to the pressure of the extrusion press applying the coating. Electrodes are then transferred to the . . .

Fig. 4 Oven Conveyor. The flux has been brushed from the holder end to permit solid contact. Between 800 and 1000 electrodes per minute are carried by the conveyor.

Fig. 5 First step in brazing rod manufacture is heating the copper alloy ingot in this gas-fired furnace to 1200° F. These 2 1/2-in. diam ingots are phosphor-copper and phosphor-silver-copper alloys

the type of container. Each of the two conveyors leads to wire-feeding machines which push the electrodes through a special die. At the die, a uniform coat of flux is extruded onto them from an extrusion press.

Flux coatings are pressed into slugs for the extrusion press. Materials are weighed on a scale which prints the weight of each constituent as it is added. Water quantities are also printed on being added, thereby giving quality control checks of all variables. Flux coatings are mixed in Muller-type mixers and given elasticity checks before being pressed into slugs.

After being coated, electrodes are given a statistical concentricity check; the tolerance is 0.002 in. They pass then into a brushing machine which brushes the flux from the holder end of the electrode. From there they go to overhead drying ovens.

These gas-fired ovens, one 250-ft long and the other 450-ft, are divided into temperature zones of 50 ft in length. Temperatures vary from 300 to 750° F. Speed of the conveyor through the ovens is controlled in each zone by Mototrol® speed controls. Location of the ovens overhead has not only permitted full utilization of floor space but also has allowed maximum dissipation of heat through large ceiling exhaust fans.

Brazing rod manufacture starts with a copper alloy ingot. This ingot is heated to about 1200° F prior to being deposited in 500-ton press for extrusion. Ingots, 2 1/2 in. in diameter, are extruded to diameters as small as 3/64-in. in a single pass.

Phos-copper® is a phosphor-copper alloy brazing rod while Phos-silver® is a phosphor-silver-copper alloy rod. The Montevallo plant also manufactures brazing rings and brazing strip.

The Montevallo plant was the third plant to be constructed by Westinghouse in Alabama in the last two years. Others are a lamp plant at Reform and a manufacturing and repair plant in Birmingham.

Repairing Cracked Milling Cutters

TEMCO Aircraft Corp. is putting cracked milling cutters back in operation the same day they are damaged.

The Dallas, Tex., firm has found that major repair on these high-carbon tools can be a routine maintenance operation. The only requirements are these: a few special fixtures, correct welding equipment and an above-average welder.

Savings from a cutter repair program are great, since milling cutters, which range in price from $30 to several hundred dollars, normally are scrapped after damage.

Cutter cracks usually result from milling machines feeding too fast, or biting too deep. In cases where matched cutters were used in pairs, a perfectly sound cutter had to be discarded if its twin was damaged. Cracked cutters now are routed to Maintenance Department Welder William P. Alberts. Mr. Alberts first fits together the two pieces of a broken circular cutter on a simple fixture he made of surface-ground boiler plate. This fixture merely serves as a level platform on which broken cutter pieces can be reassembled accurately. When fit and alignment are perfect, he secures the pieces with C-clamps and tacks them in two places with an electric arc, using a No. 680 Electrode, a high-alloy tool steel product.

This joins the pieces sufficiently so that the complete cutter can be placed on a 7- x 1/4-in. carborundum wheel. Mr. Alberts grinds a deep groove along the crack—first on one side of the cutter, then on the other. The groove allows him to get as close to a 100% weld as possible.

Tacked and grooved, the cutter is placed in another fixture for preheating and welding. This device consists of two steel rings, cut from 10-in. ID pipe. The cutter is placed between the rings which are tightened by means of four 1/2- x 4-in. bolts. Four smaller bolts, attached to steel crosspieces in each ring, are screwed tight against the cutter, sandwiched inside, further securing it.

Mr. Alberts preheats both fixture and cutter to about 700° F. He welds with Eutectic's 680 Electrode and, between tacks, he heats the work with a No. 7 tip on an oxygen-acetylene torch.

During many months of experimentation, Welder Alberts arrived at several safeguards against further cracking damaged cutters during welding. He recommends:

1. Welding from the inside (hub) of the cutter to the outside (cutting edge).

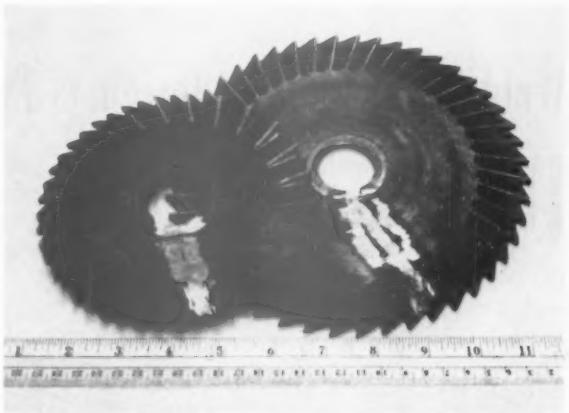


Fig. 1 This difficult welding job has been simplified by TEMCO by means of practice, a few welding fixtures and proper welding materials

Fig. 2 Ready for welding is the cracked cutter shown sandwiched inside TEMCO's welding fixture. Note that a deep groove has been ground along the route of the fracture. Welder William P. Alberts, shown holding the fixture, grooves the crack in order to get as close to a 100 per cent weld as possible

2. Keeping an equal amount of weld on both sides of the groove, and keeping the arc as close as possible to the center of the groove.

3. Getting the torch flame on the work *immediately* after each tack is made.

4. Keeping the weld balanced. For example, if the crack runs completely across the cutter, he welds briefly at one extremity, then switches to the other. By alternating in this fashion until the weld is complete, he avoids too much "pull" at any one point.

The welding operation requires about 30 min, excluding setup and preheating time. Mr. Alberts then normalizes cutter temperature and places the tool, still in its fixture, on edge inside a box to cool.

When cooling is completed and the weld is ground flush with the cutter surface, the tool is ready for service.

Welded and Bolted Design Is Feature of Record Size TV Tower

UP she goes—destination 1572 ft: This is the tapered base section and mounting pad for a new TV antenna tower being erected at Oklahoma City, Okla., for Station KWTV. At the 31-ft level, the triangular tower becomes straight sided, 12 ft on each face with one 30-ft bolted section piled on top of another (52 in all) until the 1490-ft level is reached. Then will come two RCA antennas, one 78 ft high and, on top of that, a second 73 ft high.

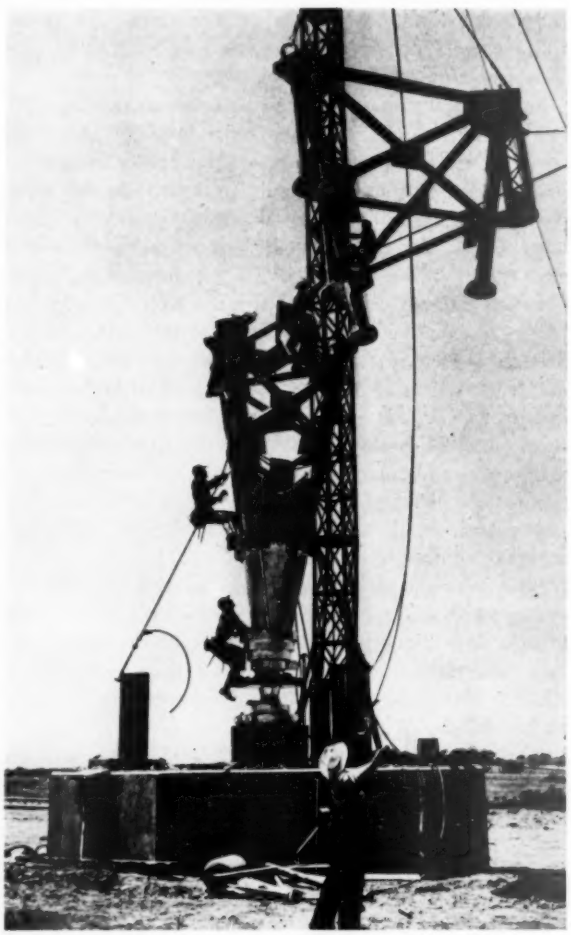
The novel structure, to be completed around September 15th, will weigh over 675 tons and rests on a series of thick steel slabs as shown carried on a composite porcelain insulator able to withstand a crushing load of 11,200,000 lb. The insulator in turn is mounted in the heavy concrete foundation which contains 1286 cu yd of concrete and 15 tons of reinforcing steel.

Wind loads are taken up by four sets of six galvanized and prestressed bridge strand guying cables, varying in diameter from $1^1/_2$ to 2 in. Cable anchor foundations are 950 ft from the tower base for the top three sets of guys, 520 ft for the lower set. The cables all make up a total length of over 5 miles.

Unusual type of construction and design, developed by the Ideco Division of Dresser-Stacey Co., Columbus, Ohio, centers around main legs of solid steel rounds, ranging in diameter from $10^1/_2$ in. down to $4^1/_2$ in. except for the lower 300 ft of the tower which has legs of 14-in. wide flange H beams, 30 ft in length and believed to be the heaviest ever rolled. Each of these beams weighs a neat 9300 lb, and they were specified because at the time it was not possible to purchase forged rounds of sufficiently large diameter.

The legs are set up in jigs at the Ideco tower shop and flanges cut from heavy slabs are welded to each end. Along the length of the leg are heavy wing or gusset plates welded all around to the surface to which girts and diagonal braces, some flat, some round, are bolted in the field.

All welding operations were expedited through the use of the Lincoln Electric Co.'s new Jetweld electrodes which carry a heavy refractory coating into which powdered iron is mixed. Welding machines are new type a-c transformers, and the result has been exceptionally fast manual welding, perhaps 50% faster than with conventional electrodes along with minimum arc blow or spatter. It is figured that close to 11,000 lb of electrode will be consumed in fabricating all the tower sections. All welded pieces are galvanized in the shop, painted with primer and rail shipped to Oklahoma. The finished structure will be painted orange and white and will mount nine flashing beacons and 18 obstruction lights to conform with CAB regulations.



Spun Steel Heads Form World's Largest Clamshell

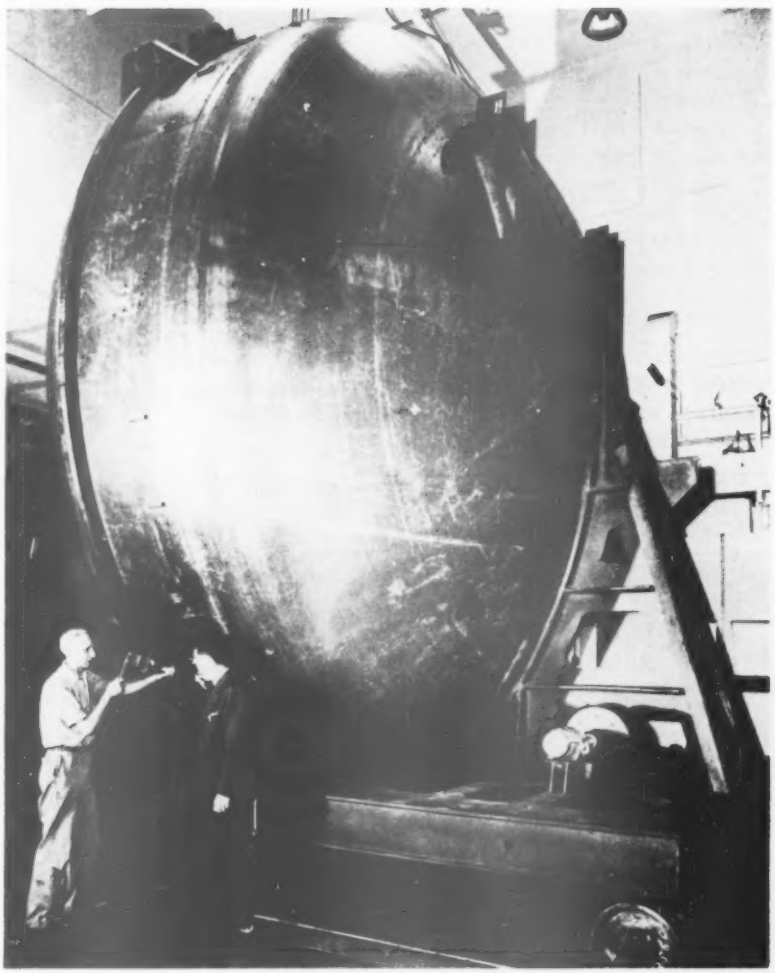
AMONG the largest and heaviest heads ever fabricated, giant steel "bowls," together weighing more than 22 tons, were recently completed by the Lukens Steel Co. for the Hamilton Standard Division of the United Aircraft Corp., Windsor Locks, Conn. They will be used to form the world's first "Clamshell"—a device for measuring the dynamic "unbalance" of airplane propellers.

The two heads for the Clamshell were spun on the largest flanging machine in the world, located in Lukens' Coatesville, Pa., mill. Each was fabricated of two $1^1/_4$-in. steel plates, welded together and cut to a disk 281 in. in diameter. The final diameter of the heads shown in the photograph is 20 ft 6 in. To give the assembled chamber the depth required for a revolving propeller and instruments, a cylinder of the same diameter was welded to one of the heads. Flanges on both heads were machined to give the tight fit required.

Although it would have been possible to fabricate the heads by welding segments together, it was considered more economical to spin them. One of the technical drawbacks thus overcome was the difficulty of otherwise achieving the accuracy required in the circular dished shapes.

Following the spinning of the giant heads, Lukens' Lukenweld Division completed the fabrication of the entire Clamshell assembly. The shallower of the two heads was fitted with supports which would allow its installation in an upright position as the stationary half of the shell. The other head, fitted with similar supports, was mounted on a 4-wheel carriage designed to run on rails to and from the fixed shell. Other fabrication details designed and installed by Lukenweld included an air circuit assembly and a drive and electrical assembly for the carriage.

When it goes into operation, the Clamshell will be used to test all propellers made at Hamilton Standard. Measurements and adjustments will be made while the propeller turns inside the chamber. Hamilton Standard engineers explain that propellers statically balanced on a system of knife edges—a standard test procedure—are not necessarily dynamically balanced at high speeds. By evacuating the chamber, aerodynamic effects on the revolving propeller blades are eliminated. Consequently, any "unbalance" that shows up can be considered strictly due to mass and can be corrected by adding weights to the blades.



Air can be evacuated from the chamber to stimulate lower pressures encountered by airplanes at altitudes up to 115,000 ft. Propellers up to $19^1/_2$ ft in diameter—among the world's largest—can be tested in the unit. Since the Clamshell operates at near-vacuum, a 125-hp motor, which is small for the propeller sizes involved, will furnish sufficient power to turn the propellers at flight speeds.

Not the least of the problems encountered by Hamilton and Lukens engineers in the enormous "Operation Clamshell" was transportation of the oversize heads from Lukens' Coatesville mill to the propeller plant near Hartford. Since they were much too large to travel the 250 miles overland, the problem was finally solved by shipping them by tug-towed barge up the New Jersey coast, through Long Island Sound, and up the Connecticut River to Hartford, a distance of some 400 miles. From Hartford to their destination at the Hamilton Standard plant in Windsor Locks, the heads went by truck, with police escort.

Large Castings Repaired by Braze Welding

by B. H. Higgs

SOME of the most durable heavy equipment is made of iron or steel castings. The need for replacing these castings is not generally anticipated, so replacement parts are not usually kept on hand. But, when a large casting develops a crack, or becomes unserviceable because of accident, what can be done?

Many users of heavy equipment have found that braze welding is an easy and economical means of repairing iron and steel castings. In addition, repairs made in this way are dependable, even under severe operating conditions. Another important feature of oxy-acetylene braze welding is that less preheating is required than for other methods of repairing cast iron. This often makes it possible to weld a casting without dismantling the machine or structure.

B. H. Higgs is with the Linde Air Products Co., Salt Lake City, Utah.

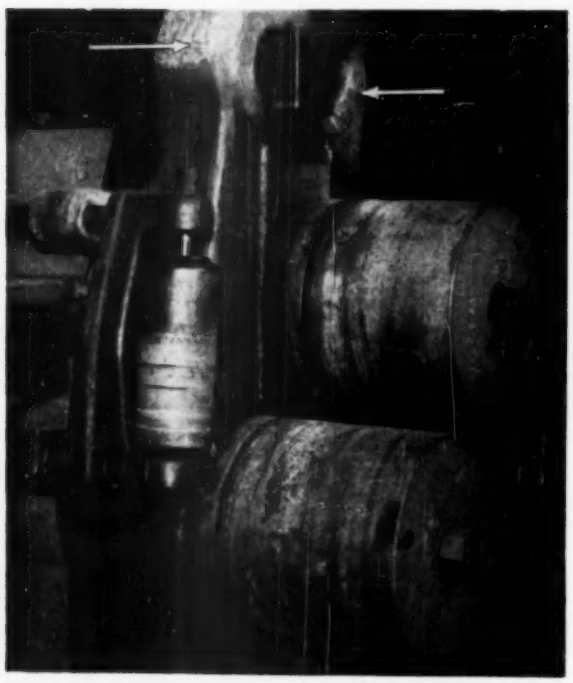


Fig. 1 Two operators braze-welded the breaks in this 2500-lb frame section of a bending roll

First, the edges of the breaks were beveled and the section was preheated. The braze-welding took 20 hr, and 90 lb of bronze-welding rod were used in the repair.

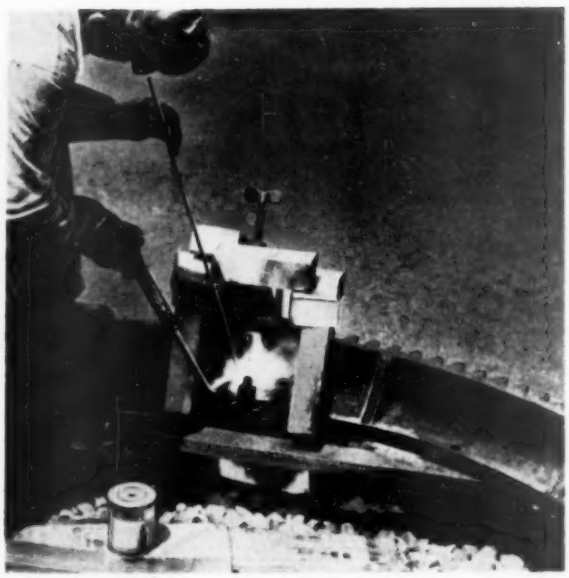


Fig. 2 This large cast-iron ring had two breaks that were braze-welded in about 8 hr

The cracks were veed, and a firebrick shield was built up around the area of each break before braze-welding was started. The firebrick helped to conserve the heat of welding.

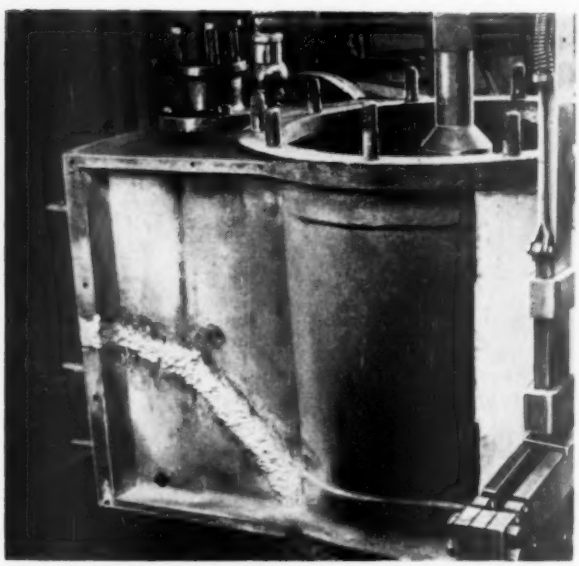


Fig. 3 The braze-welding repair of this steam chest resulted in a tug boat being returned to service within a few hours after the break occurred

Although the crack was only in the 5/8-in. thick casting, it was extended through the flange to allow expansion during welding.

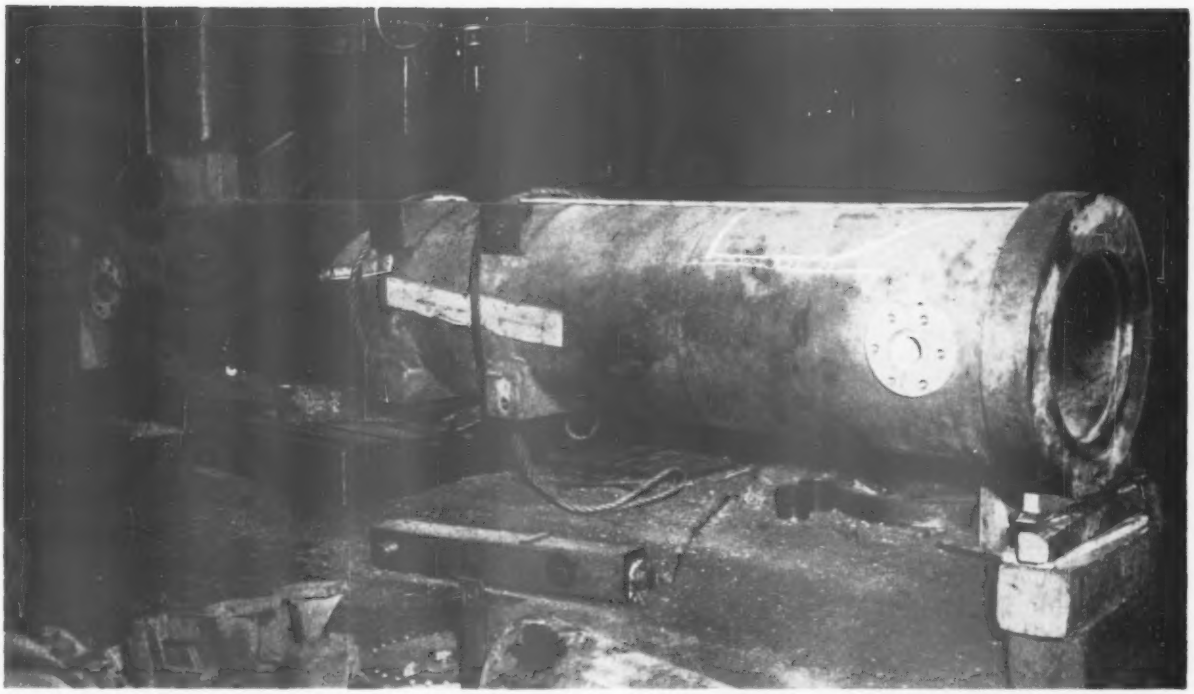


Fig. 4 Eight hundred pounds of rod and 40 lb of Brazo flux were used to repair an 8½-ft crack in this 8-ton draw bench cylinder

After a thorough preheating, four operators, working in shifts, welded the cracked casting in the fast time of 32 hr.

Some typical examples of successful braze-welding repairs are shown on these pages. These photographs show clearly that size is no barrier to good braze-welding repairs. Even the largest jobs can be braze-welded successfully at a relatively low cost.

Fig. 5 The braze-welding repair of this casting averted a lengthy shutdown, and saved a mine over $2000

Thus large rock-crusher was repaired in the mine maintenance shop after preheating with a charcoal fire. Two operators deposited 103 lb of welding rod.

Fig. 6 Two large cracks, one on each side of this cast-iron steam cylinder, were braze-welded in only 14 hr

This cylinder weighs approximately 4000 lb, and replacing it would take 12 to 16 weeks. A new casting would cost more than ten times as much as the braze-welding repair.

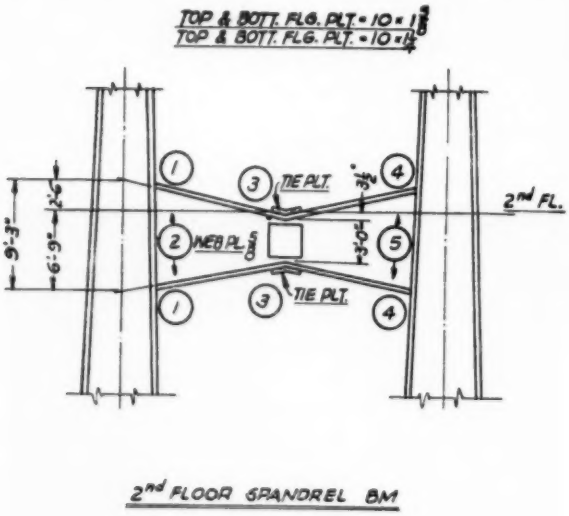
Skyscraper

San Francisco's first skyscraper since 1948 features welded tapered beams and columns

THE new 25-story Equitable Life Assurance Building now being erected in San Francisco is the first really tall building to go up under that city's strict 1948 building code. When San Francisco enacted the code in 1948, which specifies shears twice the magnitude of Unified Building Code, it was freely predicted that no more tall buildings would be erected in that city.

According to the Lincoln Electric Co. of Cleveland, Ohio, welded design was selected for critical beams and columns, both for economy and architectural reasons.

Limitation to depth of floor beams imposed by embedded duct work made it necessary to carry all lateral loads, including seismic, on the exterior walls. This meant using large columns and spandrel beams. The solution to column and spandrel beam design, complicated by splicing heavy flanges and making beam-to-column connections, was found in a continuously tapered column and tapered butterfly spandrel beam, both fabricated with the automatic hidden arc-welding process. Beam to column connections have full butt welds on the flanges and double fillet welds on the webs. The tapered columns vary from 42 x $1^1/_2$-in. webs and 18 x 3-in. flanges at the base to 12-in. webs and 16-in. flanges at the fourteenth story. Welding is being done with E6010 electrodes. If cracking in the root passes of joints in heavy sections is encountered, the root pass is made with LH-70, an E7016 electrode.



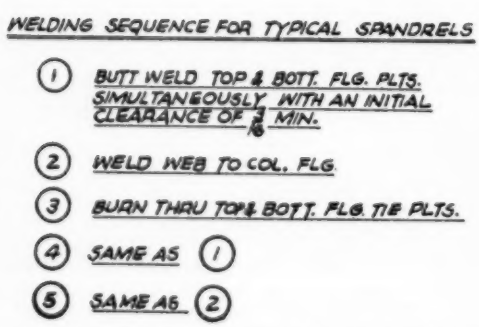

WELDING SEQUENCE FOR TYPICAL SPANDRELS
1 BUTT WELD TOP & BOTT. FLG. PLTS. SIMULTANEOUSLY WITH AN INITIAL CLEARANCE OF 3/16 MIN.
2 WELD WEB TO COL. FLG.
3 BURN THRU TOP & BOTT. FLG. TIE PLTS.
4 SAME AS 1
5 SAME AS 2

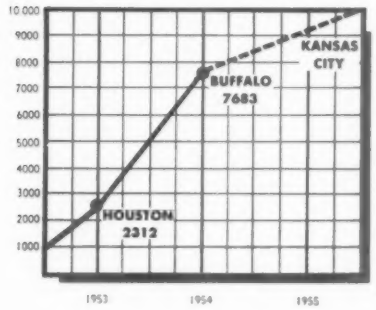
Fig. 1 Typical welding sequence for connecting tapered butterfly spandrel to tapered columns

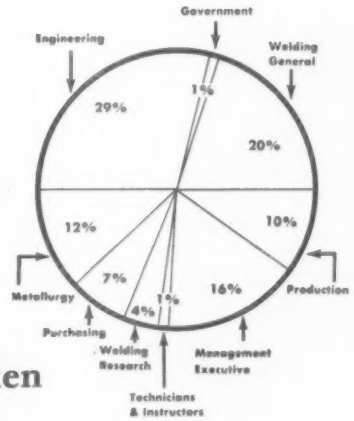
Fig. 2 The new 25-story Equitable Life Assurance Building now being erected in San Francisco

Architects are Loubet & Glynn Associates and the late W. D. Peugh; Irwin Clavan, Consulting Architect; F. W. Kellberg and Associates, Structural Engineers; Dinwiddie Construction Co., general contractor; Consolidated Western Steel Division of U. S. Steel, fabricators and erectors.

the AMERICAN WELDING SOCIETY

activities • related events





How Records Were Broken at the '54 Welding Show

The above charts give the complete story of the record-breaking attendance at the 1954 Welding Show in Buffalo. A total of 7683 persons visited the exposition. As the chart on the left shows, this was an increase of about 5300 over last year, or more than three times the attendance at the Houston Show.

The geographical breakdown of attendance, right chart, points up the significant fact that this was truly a *National Show*. Three out of four people came to Buffalo from outside New York State; about 50% traveled 300 miles, and 30% came at least 500 miles to see the latest advances in welding. This is indeed a convincing demonstration of the wide drawing power of our Welding Shows.

The center chart, giving the breakdown of registration by function or title group, shows the broad industrial and technical scope of the attendance.

36th National Metal Congress and Exposition

On Monday, Nov. 1, 1954, and continuing through Friday, November 5th, of that week, the 36th Annual National Metal Congress and Exposition—"The Metal Show"—will be held in Chicago, Ill.

The National Metal "Congress" will be held in the headquarter hotels of the participating Societies: the National Metal "Exposition" will be held in Chicago's International Amphitheatre, Halsted at 33rd St.

The 1954 Metal Show will be the ninth of this annual event to be held in Chicago.

Chicago also has the distinction of being host to the first of the National Metal Expositions, held in 1919.

The National Metal Show has also been an outstanding industrial event in Chicago: in 1926, in 1930, in 1935, in 1939, in 1943, in 1947 and in 1950.

The 1954 National Metal Exposition will be the largest of the nine held in Chicago. It will doubtless be the most significant also, since metallurgical developments have advanced to a stage where complete and thorough exchanges of information are vital to the continued growth and security of our Nation.

The size of the 1954 Metal Show can be estimated on the basis of how much space is required for its production.

According to W. H. Eisenman, Managing Director of the annual event, 263,000 sq ft of space is to be utilized for the display and operation of equipment, products and services being brought to Chicago by leading industrial firms all over the country. This represents over six acres devoted to the showing of new products, new processes, new developments and new services being offered to American industry by leaders in the metal working field.

Space in the International Amphitheatre will be occupied by 444 firms when the Metal Exposition opens on Monday morning, November 1st.

There will be a diversity of interests in the display and operation at the hundreds of exhibitor booths—ranging from new developments in spot welding to the latest in testing and finishing.

Each exhibitor will also have need for a varying amount of space—ranging from 100 sq ft to 3800 sq ft.

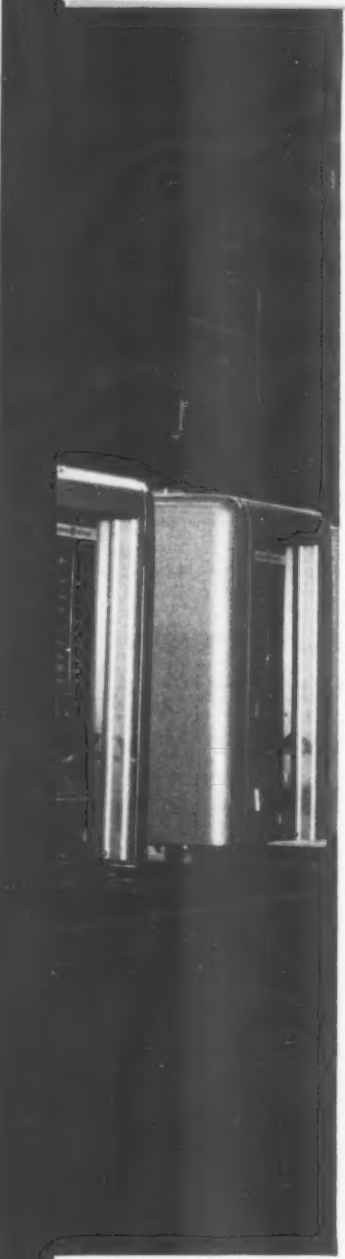
Participating with the American Society for Metals are three Technical Societies directly concerned with the advancement of science and engineering in the metals industry. These are: the AMERICAN WELDING SOCIETY; the Institute of Metals Division, American Institute of Mining and Metallurgical Engineers; and the Society for Non-Destructive Testing. Their headquarters are as follows: American Society for Metals, Palmer House; AMERICAN WELDING SOCIETY, Hotel Sherman; Institute of

WELDING ARCS NEWS

LONG-LIFE WELDERS ASSURED BY MODERN TESTING AT NEW G-E PLANT

NEW, EXPANDED G-E PLANT at York, Pa., devotes modern manufacturing-testing-facilities to new standards in arc-welding equipment. New G-E a-c welders undergo extensive quality controls . . .

PERFORMANCE TESTING of new a-c welder backs up long-life span. Every phase of operation is checked before the welder is released for production.



G.E. announces a NEW line of long-life a-c transformer welders

life-span increased with new design and materials—backed up by exacting quality controls, including 20 life-tests, 21 inspections

From its new, expanded manufacturing plant at York, Pa., General Electric now brings you industry's most modern line of a-c transformer welders. Available in 300-, 400-, and 500-amp models for indoor and outdoor service—this new equipment features improved design, new materials, and will give long, dependable service.

MOVING-COIL DESIGN REDUCES WEAR and vibration normal to other types of welder design. No moving magnetic parts are used. This low-maintenance design also furnishes accurate pinpointing of current settings for real welding precision.

IMPROVED AUTOMATIC "HOT-START" gives you the advantage of instant arc striking throughout the current range. Now you can be sure of quick starts even at the low end of the range.

PROTECTION AGAINST OVERHEATING DAMAGE caused by short-time overloads is provided by silicone insulation on aluminum-wound coils. This insulator stands up against overload temperatures which disintegrate ordinary varnishes.

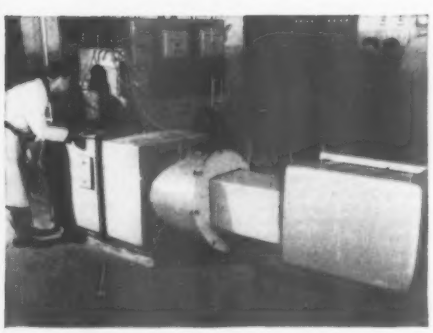
NEW ALUMINUM WINDINGS are used on transformer coils for reliable service, even under highly critical conditions.

REMOVABLE SIDE COVERS, OPEN CONSTRUCTION speed servicing. Each side cover of the G-E a-c welder can be removed quickly by simply taking out three screws.

EVEN QUIETER OPERATION than normal for a-c welders is achieved by a special vibration-insulating mount for coil supports. The moving primary coil virtually "floats," with a minimum of friction, vibration, and fatiguing noise.

IMPROVING ON EASY-TO-HANDLE ARC inherent to a-c equipment, the new G-E transformer welder provides arc stabilizing capacitors. The result is an unusually steady arc, which can be manipulated easily for faster travel speeds and increased production.

ASK YOUR G-E WELDING DISTRIBUTOR today for bulletin GEA-6243 for full details on the new long-life a-c welders. You will find his name and address in the yellow pages of your phone book, and on the next page. See this new G-E welder at the National Metals Exposition at Chicago in November. General Electric Co., Schenectady, N. Y. 710-20



PROPER COOLING OF EQUIPMENT, essential for dependable service, is checked in air-flow test, which determines the amount of air moving through welder.

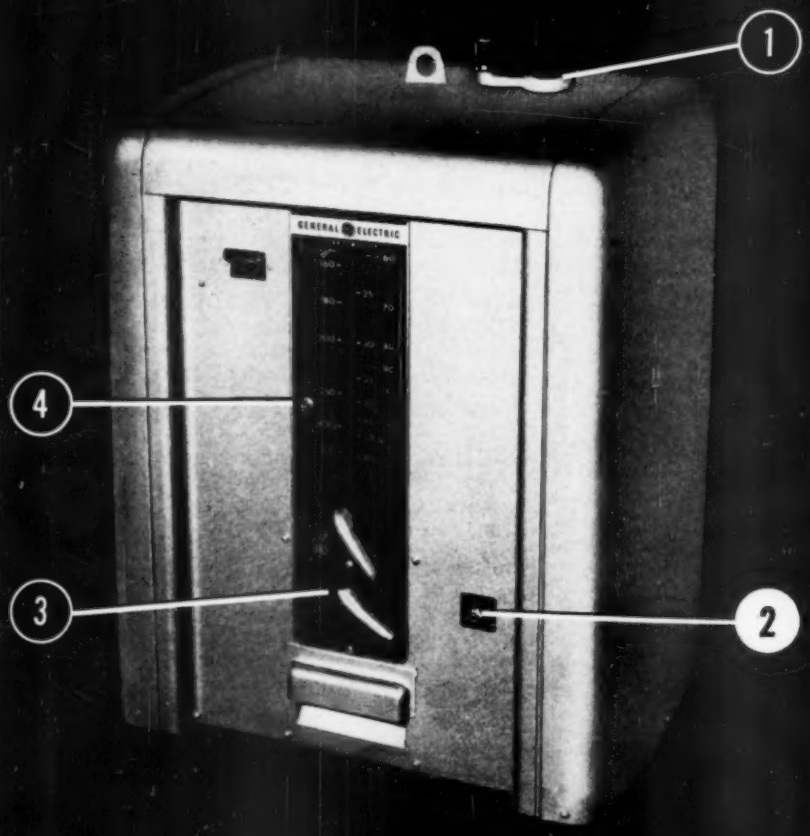
SIX TIMES RATED VOLTAGE is applied to primary coil for fifteen seconds, in testing of new a-c welder. This test assures high safety factor for silicone insulation which is used on all coil windings.

	General Electric	Company A	Company B	Company C
Moving Coil Design	✓			✓
Aluminum Windings	✓	✓		
Silicone Insulation	✓			
Hot Start	✓	✓	✓	
Arc-Stabilizing Capacitors	✓	✓		
Large Logarithmic Current Scale	✓			✓

COMPARISON WITH OTHER MAKES shows you that the new G-E a-c welder is your best buy. For more G-E welding news, turn page . . .

GENERAL ELECTRIC

NEW G-E 300-amp rectifier welder offers full-time arc-force control



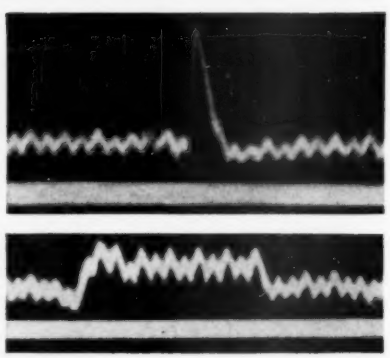
NEW G-E 300-amp rectifier welder offers *full-time* arc-force control . . . and many improved features, including—

1 **FINGERTIP-ADJUSTABLE MOVING COIL:** provides stepless current control for pinpoint accuracy, reduced wear and vibration. Current range is wide—20–375 amps.

2 **ARC-FORCE CONTROL IS FULL TIME:** doesn't cut out in the middle of an electrode. High arc force blasts away short-circuiting metal droplets, which ordinarily freeze short arcs. Results—unusual arc stability, deep penetration, and easy maneuvering.

3 **REVERSING POLARITY SWITCH:** conveniently mounted for instant changing from straight to reverse polarity.

4 **SPRING-LOADED CLEANOUT SWITCH** reverses ventilating fan for blowing dust off rectifiers—prolongs equipment life. Write your G-E welding distributor for bulletin GEA-6242.



SUSTAINED SHORT CIRCUIT occurs without arc-force control (lower oscillogram). Metal cools, electrode freezes. With *full-time* G-E arc-force control (upper), metal is blasted away, short circuit is brief.

GENERAL ELECTRIC

Contact Your G-E Welding Distributor Today

Alabama: Birmingham—Alabama Oxygen, Young & Vann Supply; Mobile—Turner Supply

Arizona: Phoenix—Consolidated Welding Supply

California: Fresno, Los Angeles, Oakland, Sacramento, San Diego, San Francisco, Ventura—Victor Equipment

Colorado: Boulder, Colorado Springs, Denver, Durango, Ft. Collins, Ft. Morgan, Greeley, LaJunta, Longmont, Pueblo, Sterling—Hendrie & Bolthoff

Connecticut: Hartford, New Haven—Harris Company

Florida: Hollywood—Florida Gas & Chemical

Georgia: Athens—Welding Gas Products; Atlanta, Macon—Welding Supply & Service; Augusta—Marks Oxygen; Columbus—Williams Welding Supplies; Gainesville—Welding Gas Products

Idaho: Boise—Gate City Steel

Illinois: Chicago, Moline, Morton, Rockford—Machinery & Welder

Indiana: Evansville—Drillmaster Supply; Ft. Wayne, Indianapolis—Sutton-Garten; South Bend—PerryWelding Sales & Service

Iowa: Des Moines—Machinery & Welder

Kansas: Wichita—Standard Products

Kentucky: Louisville—Reliable Welding; Paducah—Henry A. Petter Supply

Louisiana: Alexandria, Shreveport—Hughes Oxygen; New Orleans—Consolidated Welding Supplies

Maryland: Baltimore—Arcway Equipment

Massachusetts: Boston—New England G-E Welding Sales Division

Michigan: Detroit—Welding Sales & Engineering; Grand Rapids—Miller Welding Supply

Minnesota: Duluth—W.P.&R.S. Mars; St. Paul—Production Materials

Mississippi: Jackson—Jackson Welding & Supply

Missouri: Kansas City—Hohenschild Welders Supply; St. Louis—Machinery & Welder

Montana: Billings—Valley Welders Supply; Billings, Bozeman, Cut Bank, Glasgow, Great Falls, Havre, Kalispell, Miles City, Shelby, Sidney, Whitefish—Valley Motor Supply; Butte, Great Falls—Montana Hardware

Nebraska: Lincoln—Lincoln Welding & Supply; Omaha—Baum Iron

New Jersey: Kenilworth—Welding Sales Corp.

New Mexico: Albuquerque—Industrial Supply Co.; Hobbs—Western Oxygen; Las Cruces, Silver City—Car Parts Depot, Inc.

New York: Buffalo—Welding Equipment Sales; New York—Welding Sales Corp.; Syracuse—Welding Engineering & Equipment

North Carolina: Charlotte—Dixie Gases; Gastonia—Gastonia Motor Parts

North Dakota: Bismarck, Fargo—Acme Welding Supply

Ohio: Akron, Cincinnati, Cleveland, Columbus, Dayton, Mansfield—Burdett Oxygen; Toledo—Odland Iron Works

Oklahoma: Oklahoma City—Hooper Supply; Tulsa—G-E Welding Sales Division

Oregon: Eugene, Portland—J. E. Haseltine; Medford, Portland—Industrial Air Products

Pennsylvania: Allentown, Philadelphia, Pittsburgh—Arcway Equipment

South Carolina: Columbia, Greenville—Welding Gas Products

South Dakota: Deadwood—Hendrie & Bolthoff

Tennessee: Chattanooga, Knoxville, Nashville—Welding Gas Products; Memphis—Delta Oxygen

Texas: Abilene—M&M Welding Supply; Alice, Corpus Christi—Crane Welding Supply; Alpine, El Paso, Marfa, Pecos—Car Parts Depot; Amarillo—Welding Equipment & Supply; Beaumont—H. & W. Welding Supply; Brownsville, Harlingen—Acetylene Oxygen; Dallas—Hill Equipment & Supply; Houston—G-E Welding Sales Division; Lubbock—Welders Supply of Lubbock; Midland—West Texas Welders Supply; Odessa, Pecos—Western Oxygen; Orange—Marine & Petroleum Supply; Pecos—Welding Supply Co.; Plainview—Plains Welding Supply; San Angelo—Southwestern Welding Supply; Texarkana—Hughes Oxygen; Wichita Falls—McGinnis Welding Supply

Utah: Salt Lake City—The Galigher Co.

Washington: Seattle, Spokane—J. E. Haseltine; Seattle, Spokane, Yakima—Industrial Air Products

West Virginia: Bluefield—Bluefield Supply; Charleston—Virginian Electric; Huntington, Logan—Logan Hardware & Supply

Wisconsin: Milwaukee—Machinery & Welder

Wyoming: Cody, Lovell—Valley Motor Supply Co.

Alaska: Anchorage—Northern Supply

Canada: Toronto—Canadian G.E

Hawaii: Honolulu—American Factors, Ltd.

Metals Division, AIME, Morrison Hotel; Society for Non-Destructive Testing, Morrison Hotel.

Technical programs of the four Societies will be conducted in their respective headquarter hotels.

On Saturday and Sunday, October 30th and 31st, the American Society for Metals will hold its annual Seminar, both morning and afternoon sessions. The subject of the 1954 Seminar is "Imperfections and Impurities."

Beginning Monday, November 1st, the American Society for Metals and the AMERICAN WELDING SOCIETY will hold morning, afternoon and evening technical sessions in meetings at their headquarters hotels. The Institute of Metals Division, AIME, will hold daily and evening technical sessions beginning Monday and continuing through Wednesday. The Society for Non-Destructive Testing will hold morning and afternoon sessions Monday through Friday.

The American Society for Metals will hold its annual Metallographic Exhibit during the entire week of November 1-5. Micrographs and Macrographs displayed in this Metallographic Exhibit will qualify their owners in a contest for substantial recognition as well as a cash award for the best entry.

Managing sponsor of the 36th National Metal Congress and Exposition is the American Society for Metals. Managing Director of both events is W. H. Eisenman; Assistant Director of the 36th annual National Metal Exposition is Chester L. Wells. Headquarters for the operations of both the Metal Congress and Metal Exposition will be at 7301 Euclid Ave., Cleveland 3, Ohio. Chicago headquarters: National Metal Congress and Exposition, the Palmer House, Chicago, Ill.

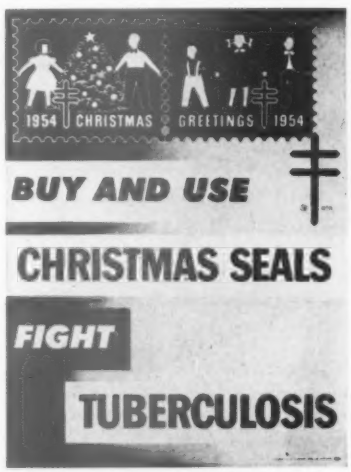
New Sustaining Member

Butler Manufacturing Co., 7400 E. 13th St., Kansas City, Mo. Manufacturer of steel buildings, propane tanks, oil storage tanks, gasoline transport tanks, grain storage tanks and bins, also, special dry cleaning equipment. Other Butler plants are located at Galesburg, Ill., Richmond, Calif., Birmingham, Ala., and Minneapolis, Minn.

Joseph M. Payne—Sustaining (A) Member Representative.

Air Reduction Co., Inc., 60 E. 42nd St., New York 17, N. Y., is a major producer of industrial gases and welding and cutting equipment. The complete line of products includes: National Carbide and acetylene generators; industrial gases—AIRCO oxygen, acetylene, argon, nitrogen and others; AIRCO oxy-acetylene welding and cutting apparatus, supplies and accessories; AIRCO electrodes, arc-welding machines and accessories; the Air Reduction-pioneered inert-gas welding process, Aircomatic; AIRCO's inert-gas process, Heliwelding, for joining thin materials; and the new AIRCOSPOT process for inert-gas spot welding of sheet steels. Technical assistance available to customers.

J. H. Humberstone—Sustaining (A) Member Representative.



FORD

AIRCRAFT ENGINE DIVISION

EXCELLENT OPPORTUNITIES AVAILABLE IN LONG RANGE JET PROGRAM FOR:

PRODUCTION PROCESS ENGINEERS (WELDING)

Process and planning background in fusion (Inert gas shielded arc) and resistance (spot & seam) welding, preferably on thin-gauge stainless steel. Must have ability to determine need for functional tooling and equipment.

PRODUCTION PROCESS ENGINEERS (SHEET METAL)

Process and planning background in stamping operations utilizing all basic sheet metal equipment. Must be familiar with functional type dies necessary for piercing, blanking, forming and drawing operations.

TOOL DESIGNERS—JIGS, FIXTURES, GAGES, DIES

Required for machining and sheet metal operations

APPLY

SALARIED PERSONNEL

7401 SOUTH CICERO AVENUE CHICAGO 29, ILLINOIS

Tentative Program

AWS National Fall Meeting

Hotel Sherman—Chicago, Ill.

November 1–5, 1954

AWS REGISTRATION—Mezzanine Floor, Hotel Sherman

Fees—AWS Members	**$2.00**
Nonmembers	**$5.00**
Sunday, Oct. 31	**3:00 P.M. to 6:00 P.M.**
Monday, Nov. 1	**8:00 A.M. to 4:30 P.M.**
Tuesday, Nov. 2	**8:00 A.M. to 4:30 P.M.**
Wednesday, Nov. 3	**8:30 A.M. to 4:00 P.M.**
Thursday, Nov. 4	**8:30 A.M. to 4:00 P.M.**
Friday, Nov. 5	**8:30 A.M. to 12:30 P.M.**

MONDAY MORNING, NOVEMBER 1st

Chairman—F. L. PLUMMER, *President*, AMERICAN WELDING SOCIETY

Co-Chairman—WALTER GOERG, JR. *Chairman*, Convention Committee

Louis XVI Room

10:00 A.M.—PRIZE AWARDS

10:30 A.M.—ADAMS LECTURE

The Toughness of Weldability
by WILLIAM L. WARNER, Watertown Arsenal

MONDAY AFTERNOON, NOVEMBER 1st—2:00 P.M.

Two Simultaneous Sessions

1—RESISTANCE WELDING

Ballroom

Chairman—CLYDE G. BASSLER
The Denton & Anderson Co.

Co-Chairman—E. A. BUSSARD
The Coleman Co., Inc.

A. Flashwelding High-Strength Steels
by W. G. FASSNACHT, Bendix Aviation Corp.

B. Effect of Post Treatment on the Properties of Flash Welds
by ERNEST F. NIPPES, WARREN F. SAVAGE, GORDON GROTKE and S. M. ROBELOTTO, Rensselaer Polytechnic Institute

C. Effects of Prestressing on Fatigue Strength of Spot Welded Stainless Steels
by V. N. KRIVOBOK, International Nickel Co., and J. A. CHOQUET and G. WELTER, École Polytechnique

2—WELDABILITY

Assembly Room

Chairman—W. D. DOTY
United States Steel Co.

Co-Chairman—JAY BLAND
Standard Oil Company

A. The Effect of Microstructure on Notch Toughness and Fracture Morphology
by JOHN H. GROSS, JOSEPH C. DANKO, and ROBERT D. STOUT, Lehigh University

B. Impact Testing Weld Metal and Heat-Affected Zone Simultaneously
by W. P. HATCH, JR., and C. E. HARTBOWER, Watertown Arsenal

C. Applicability of Charpy Test Data
by PETER P. PUZAK, MARTIN E. SCHUSTER and W. S. PELLINI, Naval Research Laboratory

MONDAY EVENING, NOVEMBER 1st

6:00 P.M.—President's Reception

Crystal and Louis XVI Rooms

8:00 P.M.—National Dinner

Bal Tabarin

Plant Visits

Arrangements have been made for two plant visits during the AWS National Fall Meeting which is to be held in Chicago, Nov. 1–5, 1954. The visits are scheduled on successive days so as to allow participation in both trips.

On **Wednesday morning, 9:00 A.M., November 3rd,** a tour will be made of the Hotpoint Co.'s new refrigerator manufacturing plant which is located in Cicero, Ill. This new plant, formally opened in October 1953, is designed and constructed to utilize the most modern equipment and manufacturing procedures. The plant occupies about one million square feet of floor space and utilizes a main assembly conveyor line 7000 ft long. This modern innovation of plant layout minimizes the materials handling problem by having the assembly line go directly into the component parts department in contrast with the usual procedure of having the component parts brought to the assembly line. During the tour several welding and brazing operations will be seen including many modern, completely automatic resistance welders, inert gas welding, oxy-acetylene welding, etc., and the latest scientific equipment and instruments used to reduce the moisture content in the refrigeration equipment to as low a point as it is humanly possible to attain. In addition, leak detectors will be seen in use which can detect leaks so small that it would take 200 years for 1 oz. of the refrigerant liquid to leak out.

On **Thursday morning, 9:00 A.M., November 4th,** a tour will be made of the Whiting Refinery and Research Laboratories of the Standard Oil Company of Indiana. The refinery proper, covering 1100 acres, is one of the largest refineries equipped to make a complete line of petroleum products. It processes an annual average of 208,000 bbl of crude oil per day with a daily gasoline output of 3,700,000 gal. In addition to gasoline, the refinery produces very sizable amounts of fuel oil (domestic and industrial), asphalt, greases, candles, insecticides, rust preventives and other chemicals. After touring the most interesting portions of the refinery, including the Welding Shop, the group will be taken through those portions of the Research Laboratory and Administration and Engineering Building which will be of interest to the AWS visitors.

WELDERS ALWAYS ASK:

"But is it as good as a Lincoln 'Shield-Arc'?"

Here's why the Lincoln "Shield-Arc" welder is *the standard of comparison* for arc welders:

1. "Shield-Arc" delivers *any* type of direct current arc... not one or two types.
2. "Shield-Arc" delivers constant output of current, regardless of line voltage fluctuations.
3. "Shield-Arc" welders are constantly improved to weld faster ... at lower and lower costs.

LINCOLN "Shield-Arc" SAE
DC MOTOR-GENERATOR WELDER
200-300-400-600-900 amps.

GET LATEST FACTS on cutting your welding costs. Send for Bulletin 459, available by writing on your letterhead to:

THE LINCOLN ELECTRIC COMPANY
DEPT. 1909 • CLEVELAND 17, OHIO
THE WORLD'S LARGEST MANUFACTURER OF ARC WELDING EQUIPMENT

TUESDAY MORNING, NOVEMBER 2nd—9:30 A.M.

Three Simultaneous Sessions

3—WELDABILITY

Assembly Room

Chairman—ORVILLE T. BARNETT
Armour Research Foundation
Co-Chairman—G. E. CLAUSSEN
Metals Research Laboratory

A. Isothermal Studies on Weld-Metal Microcracking in Mild Steel
by ALAN E. FLANIGAN and Z. P. SAPERSTEIN, University of California

B. Crack-Starter Tests of Ship Fracture and Project Steels
by P. P. PUZAK, MARTIN E. SCHUSTER and W. S. PELLINI, Naval Research Laboratory

C. Continuous Cooling Transformation Characteristics of Three Types of Weld Metal
by E. F. NIPPES and E. C. NELSON, Rensselaer Polytechnic Institute

4—RESISTANCE WELDING

Crystal Room

Chairman—WILSON SCOTT
Westinghouse Electric Corp.
Co-Chairman—E. A. SIRABIAN
Flashweld Industries

A. Spot Welding Aluminum with Single-Phase Equipment
by J. W. KEHOE and D. R. McCUTCHEON, Westinghouse Electric Corp.

B. Seam Welding Low-Carbon Steel
by M. L. BEGEMAN and GENE C. WALKER, University of Texas

C. Automatic Percussion Welding of Telephone Relay Contacts
by A. L. QUINLAN, Western Electric Co.

5—SHIELDED ARC WELDING

Louis XVI Room

Chairman—LEE H. DE WALD
National Cylinder Gas Co.
Co-Chairman—WM. C. CUNTZ
Metal & Thermit Corporation

A. Recent Developments in Contact Electrodes
by D. L. MATHIAS, Arcrods Corp.

B. Electrodes with Powdered Metal Coatings, A Progress Report
by JERRY HINKEL, The Lincoln Electric Co.

C. Metallic Rectifiers for Arc Welders
by G. K. WILLECKE, Miller Electric Mfg. Co.

TUESDAY AFTERNOON, NOVEMBER 2nd—2:00 P.M.

Section Officers Meeting

Crystal Room

TUESDAY AFTERNOON, NOVEMBER 2nd—2:00 P.M.

Two Simultaneous Sessions

6—WELDABILITY

Assembly Room

Chairman—AUSTIN HILLER
General Electric Co.
Co-Chairman—C. E. HARTBOWER
Watertown Arsenal Laboratory

A. Arc Welding Embrittlement of Powder Metals
by ALBERT SILL, JR., and C. C. MATHIAS, Sperry Corp.

B. Weldability of Wrought, High-Alloy Materials
by R. P. CULBERTSON, Haynes Stellite Co.

C. Investigation of the Performance of Weldments and Prime Plate of ABS-B Steel
by W. S. PELLINI and E. W. ESCHBACHER, Naval Research Laboratory

7—SURFACING

Louis XVI Room

Chairman—E. J. HEMZACEK
Crane Company
Co-Chairman—K. H. KOOPMAN
Linde Air Products Co.

A. High Nickel Alloy Overlays on Ferrous Metals
by GEORGE R. PEASE, H. B. BOTT and H. C. WAUGH, International Nickel Co.

B. The Inert Gas Metal Arc Overlay Process
by C. R. FELMLEY, Air Reduction Company, Inc.

C. Automatic Hard Surfacing in the Mining and Construction Industries
by I. R. BARTTER, Automatic Welding Co.

Educational Lecture Series

Old Chicago Room

Tuesday, Nov. 2nd 4:30 P.M.

Wed., Nov. 3rd 4:30 P.M.

Chairman—DR. H. UDIN
Massachusetts Institute of Technology

The Application of Temperature Measurement in Welding
by DR. ERNEST F. NIPPES
Rensselaer Polytechnic Institute

WEDNESDAY MORNING, NOVEMBER 3rd—9:30 A.M.

Three Simultaneous Sessions

8—AIRCRAFT AND ROCKETRY

Crystal Room

Chairman—R. C. HAYES
Douglas Aircraft Corp.
Co-Chairman—F. H. STEVENSON
Aerojet-General Corp.

A. Mechanical Properties of Weldments Fabricated from 356 Aluminum Alloy Castings
by W. S. TENNER, U. S. Naval Ordnance Test Station

B. Metallurgical Aspect of Welding Precipitation Hardening Stainless Steels
by C. W. FUNK and M. J. GRANGER, Aerojet-General Corp.

C. The Macro Etch System of Evaluating Quality of Resistance Welding
by D. O. SAMUELSON and F. G. HARKINS, Solar Aircraft Co.

9—TITANIUM AND MOLYBDENUM

Louis XVI Room

Chairman—S. A. HERRES
Titanium Metals Corp. of America
Co-Chairman—G. E. FAULKNER
Battelle Memorial Institute

A. Notch Toughness of Weld Deposits in Titanium Plate
by D. M. DALEY, JR., and C. E. HARTBOWER, Watertown Arsenal

B. Effect of Interstitial Elements on the Weldability of Titanium Sheet
by HERBERT M. MEYER, Armour Research Foundation

C. The Influence of Oxygen on the Joining of Molybdenum
by T. G. PERRY, H. S. SPACIL and JOHN WULFF, Massachusetts Institute of Technology

10—INERT ARC WELDING

Assembly Room

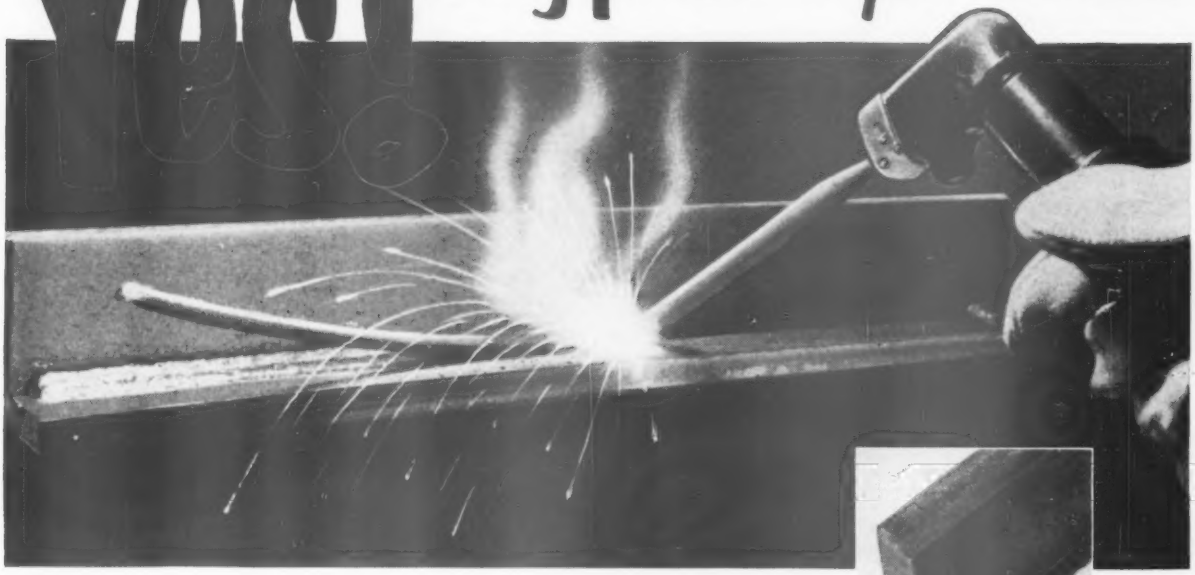
Chairman—R. C. BECKER
International Harvester Co.
Co-Chairman—A. MULLER
Air Reduction Co., Inc.

A. New Techniques in Inert-Gas-Shielded Metal-Arc Welding
by R. W. TUTHILL, General Electric Co.

B. Inert Gas Welding of Stator Packs
by F. J. PILIA, Linde Air Products Co.

C. A Production Application of Inert-Gas-Shielded Metal-Arc Welding of Mild Steel
by JOHN L. LANG, Lukenweld Division of Lukens Steel Co.

Yes! Slag peels as you weld!



Unretouched photo proves SW-44's fine ripples, good wash-up and complete absence of undercut.

New A. O. Smith SW-44 iron powder electrode offers outstanding speed, bead appearance

THROUGH RESEARCH . . . A BETTER WAY. Once again the A. O. Smith laboratories have advanced the ease and speed of welding. This time it's the SW-44 — a *perfected* iron powder electrode that's practically *self-cleaning*.

For AWS Class E-6020 work, A. O. Smith offers the job-proved SW-45 heavy-coated iron powder electrode. Here are high physicals and consistent x-ray quality plus fast deposition, good bead appearance, ease of cleaning. Like the SW-44, it's the high-speed answer for horizontal and down-hand fillet and groove welding.

Not only can you deposit far more E-6012 type of weld metal than with conventional electrodes — you *almost eliminate the job of cleaning*. What's more, bead appearance is outstanding — flawlessly smooth with fine ripples. It's as easy as squeezing tooth paste out of a tube. And re-striking is easy . . . even with a completely cooled rod.

If you haven't tried the new SW-44, see your A. O. Smith distributor today. Or you can get all the facts from A. O. Smith Corp., Milwaukee 1, Wisconsin.

Through research A.O. Smith *. . . a better way*

A.O.Smith
CORPORATION

WELDING PRODUCTS DIVISION
Milwaukee 1, Wisconsin

INTERNATIONAL DIVISION • MILWAUKEE 1, WIS.

WEDNESDAY AFTERNOON, NOVEMBER 3rd—2:00 P.M.

Three Simultaneous Sessions

11—PRESSURE VESSELS AND PIPING

Assembly Room

Chairman—I. E. BOBERG
Chicago Bridge & Iron Co.

Co-Chairman—R. A. MUELLER
Crane Company

A. The Plastic Fatigue Behavior of High-Strength Pressure Vessel Steels
by JOHN H. GROSS and ROBERT D. STOUT, Lehigh University

B. Further Studies of the Biaxial Fatigue Properties of Pressure Vessel Steels
by C. E. BOWMAN and T. J. DOLAN, University of Illinois

C. Automatic Tungsten-Inert-Arc Welding of Pipe in Position
by L. C. McNUTT, Benjamin F. Shaw Co.

12—BRAZING

Crystal Room

Chairman—A. F. CHOUINARD
National Cylinder Gas Co.

Co-Chairman—R. L. PEASLEE
Wall Colmonoy Corp.

A. Silver Brazing of Refractory Metals
by C. H. CHATFIELD, Handy & Harman

B. Filler-Metal Strengths in Brazed Copper Joints
by W. H. MUNSE and D. C. CRAWFORD, University of Illinois

C. Investigation of the Factors Determining the Tensile Strength of Brazed Joints
by NIKOLAJS BREDZS, Armour Research Foundation of Illinois Institute of Technology

13—SYMPOSIUM ON FUSED METALLIZED COATINGS

(Sponsored by AWS Committee on Metallizing)

Louis XVI Room

Chairman—H. S. HAMMOND
Metalweld, Inc.

Co-Chairman—WALTER B. MEYER
St. Louis Metallizing Co.

A. Fundamentals of Fused-on Metallizing
by BELA RONAY, U. S. Naval Engineering Experimental Station

B. Practical Applications of Fused Self-fluxing Metallized Coatings
by HARVEY S. MILLER, New England Hardfacing Co.

C. Practical Applications of Fused Non-self-fluxing Metallized Coatings
by SAM TOUR, Sam Tour & Co., Inc.

WEDNESDAY EVENING, NOVEMBER 3rd

6:30 P.M.—WRC University Dinner

Emerald Room

8:00 P.M.—WRC University Conference

Crystal Room

THURSDAY MORNING, NOVEMBER 4th—10:00 A.M.

Board of Directors Meeting

Jade Room

THURSDAY MORNING, NOVEMBER 4th—9:30 A.M.

Three Simultaneous Sessions

14—AIRCRAFT

Crystal Room

Chairman—R. S. GREEN
Ohio State University

Co-Chairman—JESSE SOHN
Curtiss Wright Corp.

A. Considerations for Fatigue in Aircraft Welding Design
by J. KOZIARSKI, Piasecki Helicopter Corp.

B. Properties of Welds in Al-Mg-Mn Alloys 5083 (LK183) and 5086 (K-186)
by L. A. COOK and S. L. CHANNON, Kaiser Aluminum and Chemical Corp., and A. R. HARD, State College of Washington

C. High-Temperature Alloy Brazing of Thin Materials for Jet Engines
by A. S. ROSE and W. N. LEWIS, I-T-E Circuit Breaker Co.

15—DESIGN AND PRODUCTION

Assembly Room

Chairman—J. E. FITZWATER
International Harvester Co.

Co-Chairman—HOWARD B. CARY
Marion Power Shovel Co.

A. Prediction of Angular Distortion Caused by One-Pass Fillet Welding
by T. KUMOSE, T. YOSHIDA, T. ABBE and H. ONOUE, Yokohama Shipyard & Engine Works, Mitsubishi Nippon Heavy-Industries, Ltd.

B. Car Building on the T & P
by H. D. HOLLIS, Texas & Pacific Railway Co.

16—CUTTING

Ballroom

Chairman—H. A. GOODWIN
Bastian Blessing Co.

Co-Chairman—J. A. HUDSON
Linde Air Products Co.

A. Oxygen Cutting with Iron Powder and Chemical Flux Additives
by R. L. DEILY and J. R. KIRWIN, Air Reduction Sales Co.

B. Inert Gas Metal Arc Cutting
by R. S. BABCOCK, Linde Air Products Co.

C. Improved Method of Oxy-Fuel Gas Combustion
by EDWARD H. ROPER, Air Reduction Sales Co.

THURSDAY AFTERNOON, NOVEMBER 4th—2:00 P.M.

Business Meeting

Crystal Room

they choose the very finest made by

The beautiful new DC-7 UNITED MAINLINER now placed into transcontinental service by UNITED AIR LINES represents the best money can buy; every minute detail for the travelers' safety, comfort, pleasure and swift transportation has been incorporated into this speedy plane. Its cost is about $1,750,000. Each individual turbo-compound engine, and there are four of them, costs some $65,000.00 and they offer the traveler a cruising speed of 365 mph. We are proud, indeed, that our company's regulators were selected a component of such an outstanding selection of construction parts as comprise this marvelous product of the engineering and construction genius of the Douglas Aircraft Company. You, too, are fully justified to place your confidence in these fine pressure regulators which today serve the most critical buyers.

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NATIONAL welding equipment company... 218 fremont street san francisco 5 california

539 DEPT 143

FRIDAY MORNING, NOVEMBER 5th—9:30 A.M.

Three Simultaneous Sessions

17—HIGH-TEMPERATURE MATERIALS

Assembly Room

Chairman—R. D. THOMAS, JR.
Arcos Corporation
Co-Chairman—G. A. ELLINGER
National Bureau of Standards

A. An Investigation of the Hot Ductility of High-Temperature Alloys
by ERNEST F. NIPPES, WARREN F. SAVAGE, H. F. MASON and B. J. BASTIAN, Rensselaer Polytechnic Institute

B. Interpreting Graphitization in High-Temperature, High-Pressure Steam Piping
by H. THIELSCH, E. M. PHILLIPS and E. R. JEROME, JR., Grinnell Co., Inc.

C. The Welding of Type 347 Stainless Steel for the Higher Steam Turbine Operating Temperatures
by R. M. CURRAN and A. W. RANKIN, General Electric Co.

18—STRUCTURAL

Ballroom

Chairman—ROBERT S. HALE
Consulting Engineer
Co-Chairman—B. G. JOHNSTON
University of Michigan

A. Behavior of Welded Single Span Frames Under Combined Loading
by C. G. SCHILLING, F. W. SCHUTZ, JR., and L. S. BEEDLE, Fritz Engineering Laboratory, Lehigh University

B. Fatigue Strength of Butt Welds in Structural Steels
by L. A. HARRIS, G. E. NORDMARK and N. M. NEWMARK, Talbot Laboratory, University of Illinois

C. New Concepts in Spot X-Ray of Welded Structures
by HAROLD HOVLAND, Industrial X-Ray Engineers

19—APPLICATIONS

Old Chicago Room

Chairman—R. L. KOHLBRY
Machinery & Welder Co.
Co-Chairman—T. B. JEFFERSON
The Welding Engineer

A. How to Apply Semiautomatic Submerged Arc Welding
by ROBERT A. WILSON, Lincoln Electric Co.

B. Mechanical Flame Descaling, Dehumidifying and Prime Coating Steel Plates
by C. H. COWAN, Higgins, Inc., and J. R. KIRWIN, Air Reduction Sales Co.

C. Automatic Hardfacing with Mild Steel Electrodes and Agglomerated Alloy Fluxes
by J. S. McKEIGHAN, The Lincoln Electric Co.

LADIES' PROGRAM

Registration and Lounge—Orchid Room, Hotel Sherman

Sunday Evening, October 31 through Thursday, November 4th

SUNDAY, OCTOBER 31st

Coffee Reception, 6:00–8:00 P.M.
Orchid Room, Hotel Sherman
This reception will provide an opportunity for meeting Chicago Section Officers and their wives

MONDAY, NOVEMBER 1st

Coffee Hour, 10:00 A.M.—Orchid Room
Luncheon, 12:00 Noon—Kungsholm, 100 E. Ontario St.
Puppet Opera, Kungsholm Theater following luncheon

TUESDAY, NOVEMBER 2nd

Coffee Hour, 10:00 A.M.—Orchid Room
Luncheon, 12:30 P.M.—Exclusive M & M Club, Merchandise Mart Building
Escorted tour of Merchandise Mart will follow luncheon

WEDNESDAY, NOVEMBER 3rd

Coffee Hour, 10:00 A.M.—Orchid Room
Luncheon, 12:30 P.M.—Wedgewood Room, Marshall Field State St. Store
Fashion Show to be held during luncheon
Escorted tour of Marshall Field's Store following luncheon

THURSDAY, NOVEMBER 4th

Buffet Luncheon, 11:30 A.M.—Orchid Room
Theater Party, 1:30 P.M.—Palace Theater—Cinerama (or sequel)
Theater party for both men and women as long as reservations are available

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WELDING AND CUTTING EXHIBITS AND DEMONSTRATIONS

NATIONAL METALS EXPOSITION

International Amphitheater
Chicago, Illinois

HOURS OF THE EXPOSITION

Monday, Tuesday and Wednesday—November 1, 2 and 3

12 Noon to 10:30 P. M.

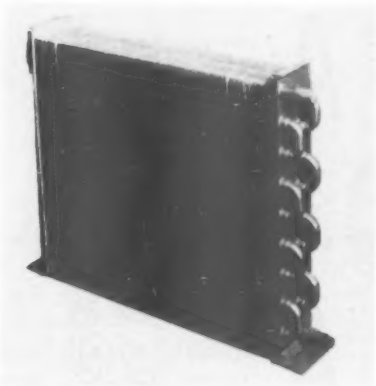
Thursday and Friday, November 4 and 5——10:00 A.M. to 6:00 P.M.

Admission by special invitation or by AWS registration badge or membership card of any participating society.

NEWS OF THE INDUSTRY

Exceptional Brazing Record

The Bush Manufacturing Co. of Hartford, Conn., manufacturers of refrigeration coils, recently reported an outstanding record in the field of metal joining. Using Phoson brazing alloy, a product of United Wire & Supply Corp., Providence, R. I., Bush brazed 7980 U-Bend joints with only three rejects. The operation



called for 24 brazing alloy rings on copper U-Bends in a continuous chain belt running through fixed torches. Each assembly was tested under 300 lb of air pressure and the tests turned up just three rejects in nearly 8000 joints. Bush also reported eight times as many units produced with low-temperature Phoson than with their old torch-and-rod method.

National Officers—American Society for Metals—1954–1955

The following will take office Nov. 3, 1954:

President: Geo. A. Roberts, Vice-President, Technology, Vanadium-Alloys Steel Co., Latrobe, Pa.

Vice-President: A. O. Schaefer, Vice-President, Engineering & Manufacturing, The Midvale Co., Nicetown, Pa.

Secretary: W. H. Eisenman, ASM National Headquarters, 7301 Euclid Ave., Cleveland 3, Ohio. (Will be serving the first year of his 19th consecutive two-year term.)

New Trustees: Walter Crafts, Associate Director of Research, Electro Metallurgical Division, Union Carbide & Carbon Research Laboratories, Niagara Falls, N. Y.; Karl L. Fetters, Assistant to the Vice-President in Charge of Operations, Youngstown Sheet & Tube Co., Youngstown, Ohio.

9th Western Metal Congress & Exposition, Mar. 28–Apr. 1, 1955

The 9th Western Metal Congress & Exposition, Pan-Pacific Auditorium, Los Angeles, Calif., will again demonstrate to the Western Metals Industries. . .and to the Nation. . that the fastest growing industrial area in America will also have the Metals Market Place of the West, beginning Mar. 28, 1955.

Managing sponsor of the 9th Western Metal Congress & Exposition is the American Society for Metals.

More than twenty Technical Societies, having Divisions in the Western States, will participate and co-sponsor the Congress & Exposition. The Los Angeles members of these Societies alone total 20,000.

Floor space of 150,000 sq ft has been made available for the showing of new products, new methods and new services.

The response from regular exhibitors and from new exhibitors has been heavy since the floor plans were released May 1, 1954.

Of the available space, 92% has been assigned to leading industries from every part of the Nation; reservations continue to come in. An attendance of 50,000 is expected at the 9th Western Metal Congress & Exposition.

W. H. Eisenman, Managing Director of the Los Angeles event, reports a total of 300 exhibitors will fill the Pan-Pacific Auditorium (largest and best in the West), as well as two additional exhibit pavilions adjacent to the Auditorium.

Technical Committees are in the process of completing a series of high level technical sessions which will be held daily during the entire week of the Western show. These Committees report that the programs being scheduled are full of merit and widespread interest to men in the metals industry.

All exhibits will be on one level.

Headquarters for the 9th Western Metal Congress & Exposition will be the Ambassador Hotel, 3400 Wilshire Blvd. The Technical Sessions and entertainment features will be held at the Ambassador.

Reservations for hotel accommodations should be sent directly to John Brady, the Ambassador Hotel, Los Angeles 5, Calif.

Hotels cooperating with the Ambassador are the Town House, Chapman Park, Gaylord, Chancellor and the Park Wilshire.

Chemical Congress

Invitations to the ACHEMA XI—Chemical Apparatus and Equipment Congress and Exhibition—to be held in Frankfurt am Main during the period May 14–22 1955, are now being issued. A pamphlet of eight pages, format DIN A4, gives a good preview of the series of functions in connection with chemical engineering and the chemical apparatus and equipment fields that the DECHEMA—Deutsche Gesellschaft für chemisches Apparatewesen—is arranging.

Over 600 firms from 12 different countries will exhibit the latest developments of their production together with their old-established lines. Many thousands of units of machinery, apparatus, equipment and complete plant, representative of all branches of chemical engineering, regulating and control equipment, constructional materials and laboratory equipment for all the varied fields of chemical research, will be on show in 11 exhibition halls of a total floor space of 46000 sq meters.

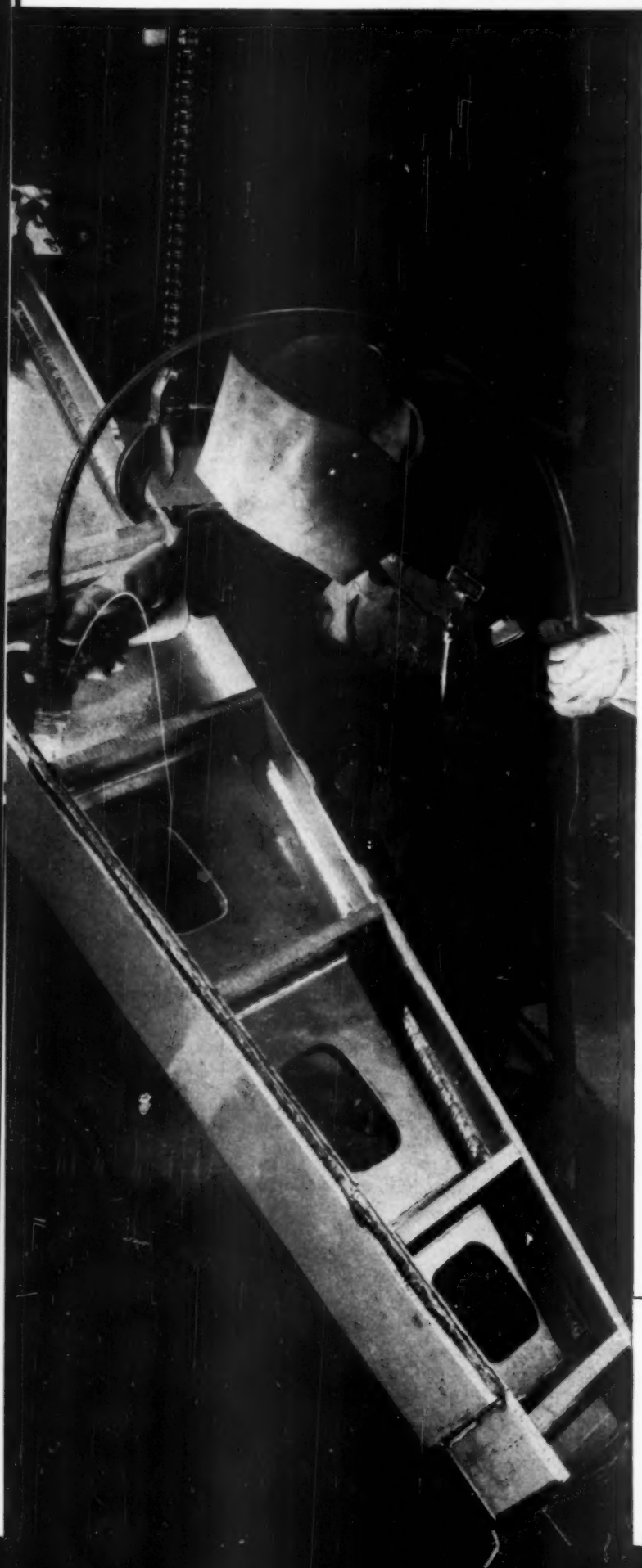
The ACHEMA XI Invitational Pamphlet, which also includes much other useful information, is issued in the Englisn, French, German, Italian, and Spanish languages. A copy of the pamphlet will be sent free of charge upon application to the DECHEMA—Deutsche Gesellschaft fur chemisches Apparatewesen, Frankfurt am Main, W 13, Postfach, Germany.

Dix Engineering Represents Kirkhof

Knowles B. Smith, General Manager of Dix Engineering Co., Inc., of Lincoln Park (Detroit), Mich. this week announced the conclusion of negotiations between Dix Engineering and the Kirkhof Manufacturing Corp. of Grand Rapids, Mich., naming Smith's firm as Sales Engineering Representatives for Kirkhof in the Detroit area.

Mr. Smith said that the engineering services of Dix, which include designing and building of special fixtures and necessary operational equipment for welding, would be augmented by the Kirkhof resistance welding transformers, special resistance welding machines and automation units.

Dix Engineering's representation of Kirkhof Manufacturing will be handled by the former company's Manufacturing Services Division.



Q: What controls the quality of consumable electrode welding?

A: One big factor is the quality of the electrode used.

Q: How can you be sure of getting the best electrode?

A: By insisting on Alcoa's new I.G.* Electrode.

Q: Why?

A: Every production lot of Alcoa® I.G. Electrode is test welded and the welds X-rayed for soundness. Each 10-lb spool is individually packed to maintain the super-smooth finish to assure soundness of weld and smoothness of feed. Each of three alloys, 1100, 4043 and 5154 (formerly 2S, 43S and A54S), is available in six diameters. There is no better electrode.

*inert gas

ALCOA ALUMINUM

ALUMINUM COMPANY OF AMERICA

A new, 176-page text, *Welding Alcoa Aluminum*, has just been released by Alcoa. It covers every phase of welding in complete detail. For a free copy, fill in and mail the coupon.

ALUMINUM COMPANY OF AMERICA
930-K Alcoa Bldg.
Pittsburgh 19, Pa.

Gentlemen: Please send book, *Welding Alcoa Aluminum*.

Name _____

Company _____

Title _____

Address _____ City _____ State _____

Q. Where is Alcoa's new I.G. Electrode available?

A. Contact your nearest Alcoa sales office, or, for immediate delivery, call one of the Alcoa Distributors listed below. He carries a complete range of alloys and sizes and you'll find him well qualified to work with your welding experts.

ALBANY, N. Y.
†Eastern Brace-Mueller-Huntley, Inc.

ATLANTA, GA.
†J. M. Tull Metal & Supply Co., Inc.

BALTIMORE, MD.
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Pacific Metal Co.

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Brace-Mueller-Huntley, Inc.
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CHARLOTTE, N. C.
Edgcomb Steel Co.

CHICAGO, ILL.
†Central Steel & Wire Company
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Corey Steel Co.

CINCINNATI, OHIO
Williams & Co., Inc.

CLEVELAND, OHIO
†The Hamilton Steel Co.
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COLUMBUS, OHIO
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DALLAS, TEXAS
Metal Goods Corp.

DENVER, COLO.
Marsh Steel Corp.
Metal Goods Corp.

DETROIT, MICH.
Central Steel & Wire Co.
Steel Sales Co. of Mich.

HARRISON, N. J.
Whitehead Metal Products Co., Inc.

HOUSTON, TEXAS
Metal Goods Corp.

INDIANAPOLIS, IND.
Steel Sales Co. of Indiana, Inc.

JACKSONVILLE, FLA.
Florida Metals, Inc.

KANSAS CITY, NORTH, MO.
†Marsh Steel Corp.
Metal Goods Corp.

LOS ANGELES, CALIF.
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TOLEDO, OHIO
Williams & Co., Inc.

TULSA, OKLA.
Metal Goods Corp.

YORK, PA.
Edgcomb Steel Co.

†Home Office

New Expansion of Victor Equipment Co.

Victor Equipment Co. has purchased a six-acre site in Whittier, Calif., for expansion of its Alloy Rod and Metal Division. Construction has already started on a 6000-sq ft plant for the manufacture of hard-surfacing alloy rods. A new furnace has been ordered and will be ready for installation when the construction on the building is completed.

Another 15,000 sq ft building will be erected when the initial construction is finished in October, according to Jack Spence, Vice-President in Charge of the Alloy Rod & Metal Division. No definite plans to move from its present Lynwood, Calif., plant are contemplated. However, it will be considered when the Lynwood lease expires in four years.

U. S. Steel Appointments

Five new appointments in United States Steel's Fundamental Research Laboratory, now located in Kearny, N. J., were announced recently by James B. Austin, Assistant Vice-President in charge of fundamental investigations in the Corporation's expanded research program.

Robert H. Aborn, Assistant Director of the Laboratory since 1947, has been named Director. Dr. Aborn has been associated with United States Steel for the last 24 years.

Lawrence S. Darken, Bernard M. Larsen, Donald S. Miller and Reginald L. Rickett, members of the Kearny staff for many years, have been named Assistant Directors, respectively, of Physical Chemistry, Metallurgical Processes, Physics and Physical Metallurgy.

Color Film

Naval Research Laboratory, Washington 25, D. C., has available a 16-mm sound, color film of explosion tests of weldments "Welding a Stronger Fleet." This film shows the method of explosion tests, the results for various types of weldments tested at various temperatures and explains why mild steels and alloy steel weldments fail in different ways. Animations are presented to illustrate the most important "factors which determine the performance of weldments." High-strength aluminum alloy weldments are included in the presentation. The presentation is intended to be entertaining as well as instructive. Running time is about 20 min.

Several prints of the film are available which can be forwarded to those desiring it at no cost.

Certification Tests

The Directorate of Procurement and Production of the Air Force has granted authority to Ohio State University's radiographic laboratory to perform X-ray radiography of materials to be used in conjunction with Air Force and Bureau of Aeronautics contracts.

The department of welding engineering, which operates the radiographic laboratory, has been notified that its certification tests are in conformance with Air Force specifications.

Radiography provides a means of examining materials for defects in welds, castings and forgings through use of X-ray or similar methods.

Ohio State's radiographic laboratory, located in the Industrial Engineering Building, has 75,000- and 220,000-v X-ray machines and is prepared to use cobalt-60 for radiographic inspection. In October, installation of a 400,000-v X-ray machine will be completed.

The radiographic equipment is used in teaching and is available for limited industrial use by arrangement with the university's Engineering Experiment Station.

Welding Utility Charges

Impartial audits of utility charges to effect savings for welding shops by selecting lowest possible rates, is a service offered by Rateonics Corp., Dallas, Tex.

After operating successfully in this field for 20 years, Rateonics is now expending nationally and has established Eastern Divisional Offices in New York City. The service is based on the premise that few utility consumers are aware of the number and complexity of electric, gas, water and steam rates on file with the Federal and State Power Commissions and that it is their responsibility—not the utility company's—to select lowest rates. Often utility bills are paid without knowledge of minimum charges which are available due to changes in equipment or other factors.

With complete rate data and legal files and an adequate engineering staff, Rateonics claims to have suggested economies for a large number of business and manufacturing concerns. Its subscribers are advised as to the lowest rates applying to their business, of any overcharges in billings, incorrect metering, or misapplication of rate schedules.

Ultrasonic Fluxless Soldering

Fluxless soldering is an important improvement in soldering techniques. It eliminates the need for a thorough washing to remove excess flux, and insures a joint free of contaminates often left by the flux. Fluxless soldering has been

IS YOUR ARC WELDING
CURRENTLY ANEMIC?
Many companies supply top quality arc welding machines and top quality electrodes to do a top welding job but miss one extremely important point . . .
. . . The performance in the arc is entirely dependent upon the cables and accessories that bring the welding current to the electrode from the machine's terminals.
Is your arc current starved due to poor connections at lugs, quick connectors, grounds and in holders?
Do your operators have to stop occasionally to cool off electrode holders due to hot handles caused by poor connections or use two holders where one should do the job?
Does your weld quality suffer due to volt and amperage variations during the welding cycle?
You can eliminate these troubles. Just specify CADDY Accessories and cable splices using 100% solid copper CADWELD connections throughout.
CADDY alone gives you a 100% Copper Circuit from the power line through the welding machine right to the electrode.
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WRITE TODAY FOR NEW 1955 CADDY CATALOG

made practical by high-powered ultrasonic equipment recently put on the market.

Sonobond, developed by Aeroprojects, will tin aluminum, copper, magnesium and silver without the use of any flux. This equipment is being built with sufficient ultrasonic power to tin these metals readily on a production basis.

Aeroprojects' soldering shop, at West Chester, Pa., has been using Sonobond for a year and a half. Experimental or production orders of 1 to 10,000 parts are run in this pilot plant. In this way companies interested in the new process can prove its usefulness as a production method before the purchase of equipment. When a company is satisfied with the process, and production methods have been worked out, it can then procure the equipment best suited to its needs and install the operation in its own plant.

Sonobond is simple to operate and requires no particular skill on the part of the operator. Aeroprojects' Pilot Plant operation demonstrates how simply jobs can be handled and how superior soldered joints can be made with fluxless soldering using Sonobond.

Oxweld Railroad Service Co. Combines with Linde

Effective September 1st, Oxweld Railroad Service Co. will combine with Linde Air Products Co., which has formed a new Railroad Department, to conduct the business now handled by the Service Co. Both companies are Divisions of Union Carbide and Carbon Corp.

Oxweld Railroad Service Co. has served the railroads of the United States for more than 40 years by selling the gases, apparatus, carbide, and supplies for oxyacetylene welding and cutting, and more recently also for Heliarc and Unionmelt welding. Since the discontinuance of the Service Co.'s "service contract" with the railroads, however, the method of doing business has been the same as that of Linde Air Products Co.

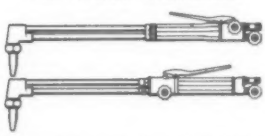
As the two companies have been carrying on a similar business, and so that customers may be better served and have the full benefit of combined knowledge and facilities of both organizations, the two Divisons of Union Carbide have been combined.

K. I. Thompson, formerly Vice-President in Charge of Sales for the Service Co., has been appointed Manager of the Railroad Department of Linde Air Products Co., with headquarters in New York. The present organization of personnel of the Service Co. will become the Railroad Department of Linde.

Attend Fall Meeting
A.W.S.
Program in this issue!

NO JOB TOO HOT ...OR TOO TOUGH *for THESE cutting torches!* *

* VICTOR'S NEW
Series 1000
Series 1100
CUTTING TORCHES



CHOICE OF LEVER POSITION . . . cutting oxygen lever pivots from top rear of handle on Series 1000; from top front on Series 1100. Both Underwriters' approved. Available with 45°, 75°, 90° or 180° heads, to take all VICTOR standard-type tips.

LICK YOUR HOTTEST JOBS
without a flashback . . . solid stainless steel mixing tube absorbs heat slowly, keeps gases below flashpoint.

LAST LONGER UNDER ROUGH, TOUGH USE
because they're made of toughest materials . . . special heat resisting bronze heads, stainless steel tubes, forged brass bodies.

EASIER TO HANDLE, EASIER TO MAINTAIN
. . . hand-fitting oval shaped bodies, perfect balance give precise control. Design is simplicity itself; you can take either model apart completely, then reassemble it, all in less than 5 minutes!

Make your tough jobs easy, your easy jobs a pleasure — see your VICTOR dealer now!

VICTOR for welding

VICTOR EQUIPMENT COMPANY

Mfrs. of welding & cutting equipment; hardfacing rods; blasting nozzles.

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LOS ANGELES 58

844 Folsom Street
SAN FRANCISCO 7

IF YOUR PRODUCT IS WELDED A.W.S. CAN HELP YOU!

Many of the advancements in welding design these days spring directly from the membership of the American Welding Society.

Most of the engineers in welding industries depend on A.W.S. to keep in touch with technological advancements outside the boundaries of their own plant and their own day-by-day welding experience.

Many of their achievements in saving weight, improving products and reducing manufacturing costs can be traced directly to discussions and exchange of ideas at their frequent A.W.S. section meetings.

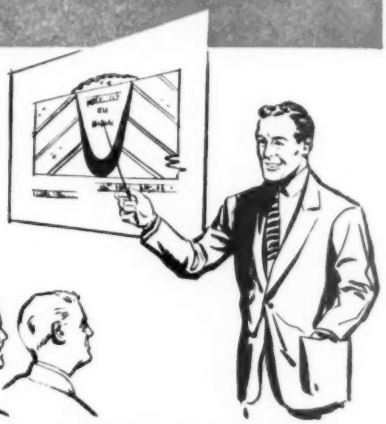
If you use welding in your business, make sure that your welding people are taking full advantage of the opportunities A.W.S. offers.

This giant welded sheave is 15 feet in diameter, the hub is a center bored forging, and the entire weldment weighs 34 tons. — Photo courtesy Bethlehem Steel Co.

A. W. S. Builds "MEN OF WELDING"

There are 66 active local sections of A.W.S. covering the entire United States. The 9,683 members of A.W.S. hold monthly technical meetings and plant visitations where they observe practical solutions to typical welding problems and study new welding methods. They receive accurate information on welding design, fabrication and maintenance through discussions with the best welding minds in the nation and authoritative printed reports.

"Men of Welding" advance in their profession through technical meetings and group discussions on welding methods and practices.



AMERICAN WELDING SOCIETY

A powerful force in welding progress since 1919

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YOUR COMPANY can participate through a sustaining or supporting membership. Get the facts about A.W.S.

AMERICAN WELDING SOCIETY, 33 West 39th Street, New York 18, New York

10/54

Please send me more information on the personal and company advantages of membership in A.W.S.

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TITLE_____ CITY_____ ZONE____ STATE_____

PERSONNEL

ASTM Honors Sam Tour

At the 57th Annual Meeting of the American Society for Testing Materials, Sam Tour, President of Sam Tour & Co., Inc., was honored by an Award of Merit "for long and fruitful service to the Society extending over many technical fields and administrative phases, for work on test methods, and especially for contributions to the metals and corrosion fields."

Mr. Tour's participation in ASTM's activities started 33 years ago. During these years he has become well known for his contributions on testing machines and on impact, stiffness, salt spray and corrosion testing. Notable also are his papers on corrosion of nonferrous alloys, die castings, aluminum alloys for pressure die casting, zinc-base die-casting alloys, nomenclature and classification of cast copper and copper-base alloys.

A member of 14 different technical committees and 35 different subcommittees in this time, Mr. Tour has served as Chairman for ten years of Committee B-7 on Aluminum and as Chairman for four years of Committee B-3 on Corrosion of Non-Ferrous Metals. In addition, for 18 years he was secretary of the latter. He has served as an elected Director of the Society for three years and is the author of numerous items appearing in the Proceedings of ASTM for 25 out of the last 33 years.

Mr. Tour, who is a Licensed Professional Engineer and a Member of the AWS maintains his Research and Testing Laboratories at 44 Trinity Place, New York City.

Magnaflux Officers

The Board of Directors of Magnaflux Corp. announced several advancements within the corporation management. This company develops and supplies methods for nondestructive testing to every industry in the country.

F. B. Doane was elected Chairman of the Board of Directors, in addition to his duties, since 1944, as President. Carl E. Betz is the newly appointed Vice-Chairman of the Board of Directors. Mr. Betz has been Executive Vice-President since 1946. W. E. Thomas will now assume the title and duties of Executive Vice-President, after serving since 1946 as Vice-President—Sales. Messrs Thomas and Betz are members of the AMERICAN WELDING SOCIETY. Wylie D.

C. E. Betz

Reid, Jr., has been named Treasurer, in addition to his duties as 2nd Vice-President and Plant Manager.

It is noteworthy that Mr. Doane was one of the founders of the company, and assumes the position as Chairman of the Board during the 25th Anniversary Year of its operation. Mr. Betz also, has been active in the company during most of its 25 years of growth. Magnaflux Corp. created and pioneered many of the most widely used test methods to locate cracks in production without harm to the part. These test ideas were new and their availability to industry has permitted the development of lighter and stronger products of all types, because each part could be tested and known to be crack-free and fully reliable. These inspection developed by the company also save millions of dollars in thousands of plants, because parts can be tested and proved good in the rough state, so that manufacturing time and labor is spent only on good parts.

Each of the above Officers has contributed personally to the growth and development of Magnaflux for at least half of its life. Each is recognized in industry for contributions to the new testing methods which make the products of American Industry safer, lighter and more reliable.

W. E. Thomas

Boring Made District Manager

Tweco Products Co. has announced the appointment of Donn Boring as Eastern District Manager. He will be responsible for the sale of Tweco Products in the 14 eastern states.

Donn Boring

Mr. Boring has been with Tweco since June of 1952 and has been active in the sales and advertising department at the factory in Wichita, Kan. Prior to joining Tweco, Mr. Boring was active in the welding industry in Canada for more than 15 years.

Mr. Boring who will make his home in Roseland, N. J., is a member of the AMERICAN WELDING SOCIETY.

Typical Fillet Speeds

Electrode Size	Amps., AC	Fillet Size	Speed, in./min.
3/16"	290	1/4"	15
7/32"	325	5/16"	15
1/4"	395	3/8"	15

Deposition Rates

DH-5 Electrode Size	DH-5 Amps.	DH-5 Deposit #/hr.	E-6012 Deposit #/hr.
3/16"	250	6.8	4.5
3/16"	280	7.9	
3/16"	320	9.6	
7/32"	300	9.0	5.8
7/32"	340	10.1	
7/32"	380	12.0	
1/4"	350	11.2	7.0
1/4"	400	12.8	
1/4"	450	14.7	

Try to match this for

You can't — unless you use the . .

Deposits up to twice as many pounds per hour as an E-6012

That's right, the DH-5 is in a class by itself, when it comes to high welding speed and sound deposits in horizontal and flat positions. It's Harnischfeger's answer to the demand for lower welding costs. It's your answer to the need for faster, better work.

Powdered metal in the coating becomes part of the deposit — increases thermal energy and efficiency. By simply dragging the DH-5, the operator gets the speed and bead appearance ordinarily associated with submerged arc welds.

Wherever they've tried it, weldors like the DH-5. It's fast, it's easy to use. There's no splatter. Slag removal is easy and quick. The bead shape is flat and smooth.

The DH-5 has good, as-welded, mechanical properties, too. See for yourself:

Tensile strength - - -	85,000-95,000
Yield strength - - - -	73,000-77,000
Elongation in 2" - - - - -	15-25%

If you're interested in your cost picture — and who isn't, today?—you owe it to yourself to try the DH-5 without delay. See your P&H representative or distributor now.

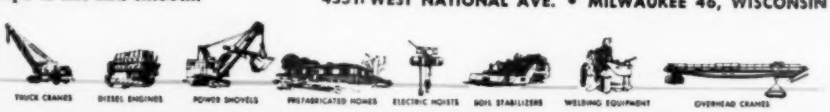
For further facts, write for bulletin.

P&H WELDING DIVISION

HARNISCHFEGER CORPORATION

4551 WEST NATIONAL AVE. • MILWAUKEE 46, WISCONSIN

the P&H Line



high-speed welding!

New P & H DH-5 Electrode

America's most complete line of arc-welding equipment and electrodes

P&H DC RECTIFIER WELDER

Four sizes — 200, 300, 400 and 500 amps (NEMA-rated). No moving coils to break down — no bearings, brushes, commutator, brush riggings, etc., to replace. Dial-lectric Control gives you fingertip heat-control at the work.

P&H AC WELDER

A full range of sizes up to 625 amps (NEMA-rated). All are connectable to 220 or 440 volts. Dial-lectric Instantaneous Remote Control is fingertip control — gives you any heat you want, right at the work.

P&H POSITIONERS

One finger is enough to position heavy weldments for economical downhand welding. Capacities from 2500 to 36,000 lbs. — remote-control and hand-operated models.

P&H WN-250 ENGINE-DRIVEN ARC WELDER

NEMA-rated at 200 amps, but pulls 300 amps. Has full 20-gallon gas tank — runs all day on one tankful. Powered by four-cylinder, 180 GLU, Waukesha, water-cooled gasoline engine.

P&H Welding equipment is manufactured and sold in Canada by

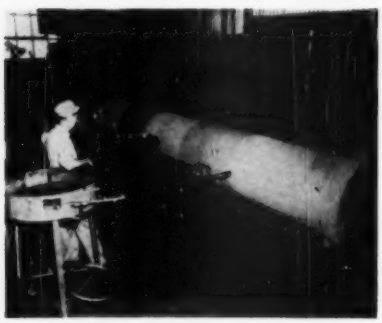
REGENT EQUIPMENT MANUFACTURING COMPANY LTD.

455 King Street West • Toronto, Ontario, Canada

NEW LITERATURE

Service Life Increased

The current issue of the *Metco News* describes and illustrates a large number of money saving metallizing applications. Among these is the experience of a petroleum company with its gasification tubes.



These tubes, used for heating liquid are 24 in. in diam and 20 ft 6 in. long. Exposed to high temperatures the life of the tubes was relatively short due to heat oxidation and scaling. Six tubes were treated in 1944 with such excellent results that 12 more were metallized in 1949. Since the useful life of these tubes can be lengthened indefinitely by retouching wherever signs of attack appear, there seems to be no practical limit to their continued use.

Another metallizing job also described in this issue is that of restoring the press fit and slip fit on end bells of Diesel generators. Welding had been tried and abandoned because of heat warpage and high-refinishing cost. Formerly junked these $400 parts are now rebuilt for $30—a saving of $370 each.

Many other applications are illustrated, among them a railroad axle, compressor water jacket, generator pulleys, sprayed metal molds, pistons, etc. For your copy write to Metallizing Engineering Co., Inc., Westbury, L. I., N. Y.

Metal Powders

Bulletin No. 1, recently issued by Plastic Metals Division, The National Radiator Co., Johnstown, Pa., provides a brief introduction to the art of powder metallurgy. In addition the bulletin describes the general types of metal powder offered by Plastic Metals and stresses the large number of grades required for different applications.

Also included in the leaflet are references to some of the other major uses for metal powders such as in cutting tools, chemical applications, flame-cutting, welding rods, pyrotechnics and the fabrication of special electronic and magnetic parts.

Resistance Welding Alloys

The Welding Sales and Engineering Co., 8750 Grinnell Ave., Detroit 13, Mich. has just issued a new 24-page pamphlet describing their Tuffaloy Resistance Welding Alloys. This booklet represents the Tuffaloy line in as much practical detail as space and specification permit. Copy available on request.

Resistance Welding Bulletin

Sciaky Bros., Inc., 4915 W. 67th St., Chicago, Ill., Vol. 3, No. 7, *Resistance Welding at Work*, covering case history of Sciaky electric resistance welding equipment as used at the Moloney Electric Co., St. Louis, Mo., the largest manufacturers of transformers in the world.

This case history is an interesting example of Sciaky three-phase electric resistance welding of spot, seam and projection welding of distribution transformer tanks to rigid specifications.

Fine examples of electric-resistance welding pictures, as well as interesting techniques of spot, seam and projection welding are described.

To receive your copy of Vol. 3, No. 7, *Resistance Welding at Work*, write direct to the Chicago plant.

Resistance Welding of Copper Alloys

A new Bulletin in their series on various phases and applications of Resistance Welding has just been released by the Resistance Welder Manufacturers' Assn. Designated as Bulletin No. 20, it covers the *Resistance Welding of Copper and Copper Base Alloys.*

Consideration is given in the Bulletin to the various factors entering into the weldability of copper and copper base alloys, as well as the technical aspects of the welding processes recommended.

The 9-page Bulletin contains a number of helpful tables and illustrations.

Copies are available at the headquarters of the Resistance Welder Manufacturers' Assn., 1900 Arch St., Philadelphia 3, Pa., at ten cents each.

Hand Torches

Air Reduction is offering a new 36-page catalog covering their complete line of torches and tips for oxy-acetylene cutting and welding.

Every Airco standard torch and tip is listed along with the necessary mixers, extensions, adapters and accessories that are used with the torches. Complete information is presented through carefully planned illustrations, charts and descriptions.

Request a copy of this catalog, ADC 702B, by writing to Air Reduction Sales Co., 60 E. 42nd St., New York 17, N. Y.

Resistance Welding

Sciaky Bros., Inc., 4915 W. 67th St., Chicago, Ill., have issued Vol. 3, No. 9 of *Resistance Welding at Work*, covering the case history of Sciaky electric resistance welding equipment as used at Casco Products Corp. in Bridgeport, Conn., manufacturers of simulated wire wheels for automobiles.

This case history is an interesting example of cross wire welding simulated wire wheels for automobiles to exacting specifications on a Sciaky standard three-phase welder which joins all 42 parts of the wheel at a production rate of over 1000 assemblies per day.

To receive this interesting technique of cross wire welding which is described in detail and well illustrated with plenty of on-the-job photos, write direct to the Chicago Plant for copies of Vol. 3, No. 9.

Accident Preventers

"Accident Preventers"—the National Safety Council's new employee training leaflets—are packed with illustrations and sound tips on how to stay safe on the job.

Using few words but plenty of colorful cartoons, the preventers teach safety to today's worker who is accustomed to the fast visual presentation of television and the picture magazines.

Here is a pocket-size library of safe principles and practices on lifting, housekeeping, clothing and hand tools which can be used in many ways. They may be distributed at safety meetings, passed out by foremen, enclosed in pay envelopes or made available for pick-up at the time clock.

For sample copies and quantity prices write the National Safety Council, 425 N. Michigan Ave., Chicago 11, Ill.

Quenched and Tempered Steels

Tensile and Impact Properties of Quenched and Tempered Nickel Alloy Steels in Different Sizes—Bulletin A-68, 36 pages. Over 70 mechanical property charts show the properties which may be regularly expected in the nickel alloy steels in various section sizes. General characteristics of each type briefly described as an aid in the selection of steels for particular applications. International Nickel Co., New York 5, N. Y.

Copper Welding Alloys

A 4-page, fully illustrated news sheet, has been issued by Eutectic Welding Alloys Corp., Flushing, N. Y., on its newly developed copper and copper base welding alloys. Five new alloys are listed each with distinctive properties and each designed for a specific purpose. They were developed following extensive market research which revealed an industrial need for these new type alloys.

EutecTrode 280 DC, an arc electrode, has unusual weldability, high-tensile strength and excellent corrosion resistance on copper and copper alloys. It may be used for joining ferrous metals and copper alloys.

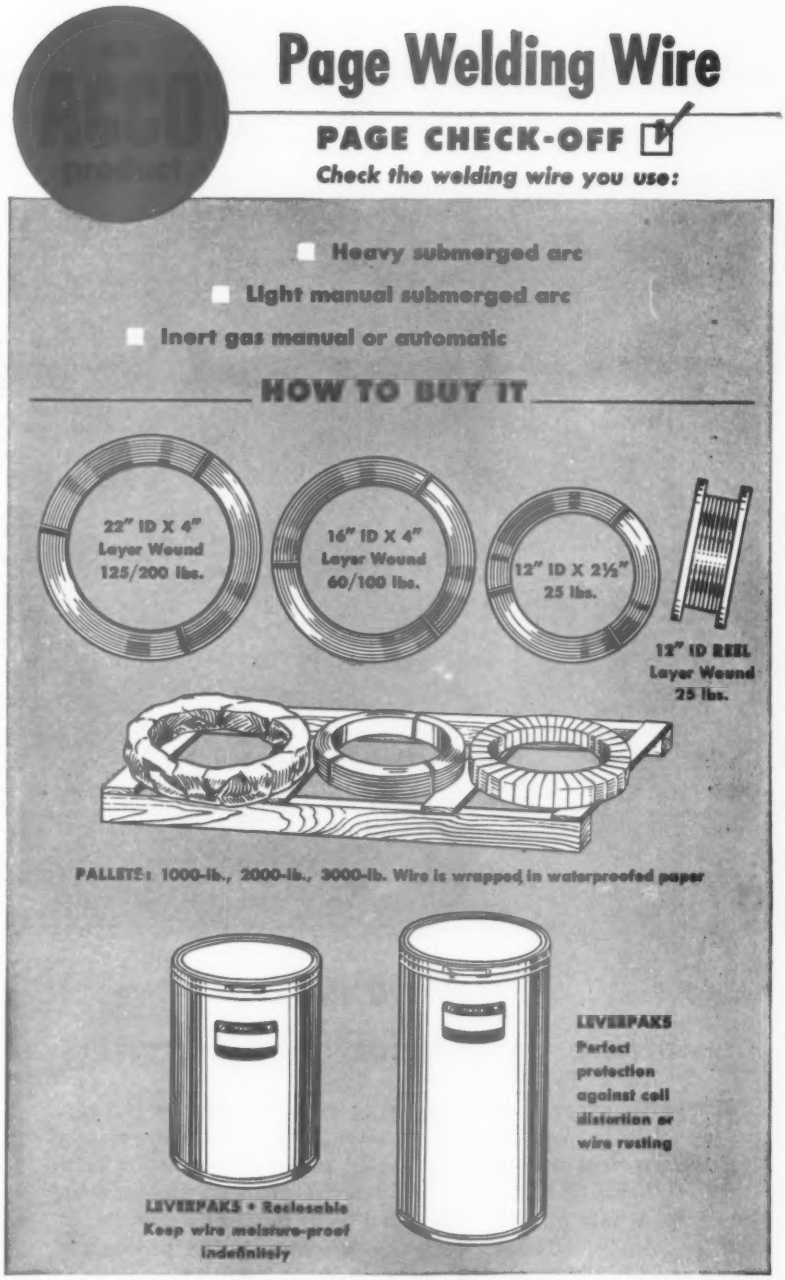
EutecTrode 300 DC, deposits practically pure copper and may be used without preheating the base metal. The high thermal conductivity of copper is overcome because the special coating permits the electrode to act as the heating agent when a long arc is held. When the arc is shortened, deposition begins and deposits resemble those of an inert gas weld.

EutecTrode 1850 AC and 1850 DC supply the answer to many copper and bronze welding problems. The lengthy preheating necessary for torch brazing is eliminated. Operations can be completed in one-fifth of the time and with considerably less heat input.

EutecTrode 1840 DC was developed for weldments which required maximum machinability. It has similar characteristics to 1850 with the same ease of application. Welds are claimed to be 50% stronger than those applied with a torch technique.

Eutec-CopWeld, a copper solder in paste form, although primarily designed for production work, can be used wherever close-fitting, high-strength joints are required on copper or copper alloys. The material can be painted onto the part and when heat is applied a high-strength joint with excellent appearance and high strength is obtained.

Copies may be had free of charge by writing to Eutectic Welding Alloys Corp., 40-40 172nd St., Flushing 58, N. Y. (ask for Vol. I, No. 11, TIS 2263).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Electrodes

Complete descriptive information along with application and procedure data on all Murex mild steel and low-alloy arc-welding electrodes are included in a new 30-page catalog now being offered by Metal & Thermit Corp. Designed to be helpful in selecting exactly the right electrode for the job in hand, the new Murex catalog also contains formulas for estimating welding costs, heat treating procedures, hardness conversion tables, and other useful reference material for the welding engineer, metallurgist and welding foreman. Copies are available from the company, whose headquarters are at 100 E. 42nd St., New York 17, N. Y.

Safety Standards

A completely revised edition of the *Handbook of Industrial Safety Standards*, a recognized classic in its field for more than 30 years, is now available, the Association of Casualty and Surety Companies announced recently. The handbook has been developed by the Accident Prevention Department of the Association, with the assistance of outstanding engineering specialists of the Association's member insurance companies.

The new ninth edition, which is 50% larger than the previous edition, includes several new chapters, illustrations and tables in its 315 pages.

Encompassing 38 chapters and four appendices, the handbook is a concise but comprehensive compilation of industrial safety requirements recommended by nationally recognized authorities including the American Standards Assn., the National Fire Protection Assn., the American Society of Mechanical Engineers and various governmental organizations. However, much of the text material is an amplification and extension of the various codes on which it is based, and some sections deal entirely with topics not covered by any existing standards.

The subject matter of the handbook runs the gamut of industrial safety topics including: safety programs, accident investigation, materials handling, boilers and unfired pressure vessels, machine guarding, illumination, exhaust systems, electrical equipment, spray coating, tank operations, building exits and prevention of "off-the-job" accidents. Completely new chapters have been added on welding and cutting, storage and handling of flammable liquids, radiation hazards and disaster control. Included in the appendices are an index to American Safety Standards, a table of maximum allowable concentrations of toxic substances and a classification of fire extinguishing appliances.

Copies may be obtained from any of the Association's 113 member companies or directly from the Association at 60 John St., New York 38, N. Y. The price is $1.40 per copy.

Steel Piping Materials

The 1954 edition of this compilation sponsored by ASTM Committee A-1 on Steel contains in their latest approved form the 53 widely used ASTM specifications for carbon-steel and alloy-steel pipe and tubing, including stainless.

Materials covered include: pipe used to convey liquids, vapors and gases at normal and elevated temperatures; boiler, superheater and miscellaneous tubes; still tubes for refinery service; heat-exchanger and condenser tubes. To make the volume more complete there are also included specifications for the following materials used in pipe and related installations: castings; forgings and welding fittings; bolts and nuts. The ASTM standard classification of austenite grain size in steels (E19) with two sets of charts; also the American Standards covering wrought steel and wrought iron pipe (B36.10) and stainless steel pipe (B36.19) are a part of the book.

In this special compilation, 22 of the specifications included in the previous edition have been revised; of this number, 17 are tentatives and 5 are standards. A new specification covers ferritic alloy steel forged and bored pipe for high-temperature service.

Copies of this 370-page, heavy-paper-covered publication can be obtained from Headquarters of the American Society for Testing Materials, 1916 Race St., Philadelphia 3, Pa., at $3.75 each.

Hazards in Metalworking

In recent years the metalworking industries have been beset by fire. Since 1942 large-loss fires in both heavy and light metal working plants have increased 17 times. This is due in part to higher concentration of values in buildings, equipment and products exposed to fire and to hazardous new auxiliary processes and mixed occupancies.

These facts are brought out in a 57-page survey on fire hazards and safeguards for metalworking industries issued recently by the National Board of Fire Underwriters.

According to the National Board, there were about 175 large-loss fires—those that result in damage of $250,000 or more—in the metalworking industries between 1942 and 1953, with an aggregate loss of approximately $150,000,000 as contrasted with the period from 1931 to 1942, when only 18 large-loss fires were reported with aggregate losses of $8,500,000.

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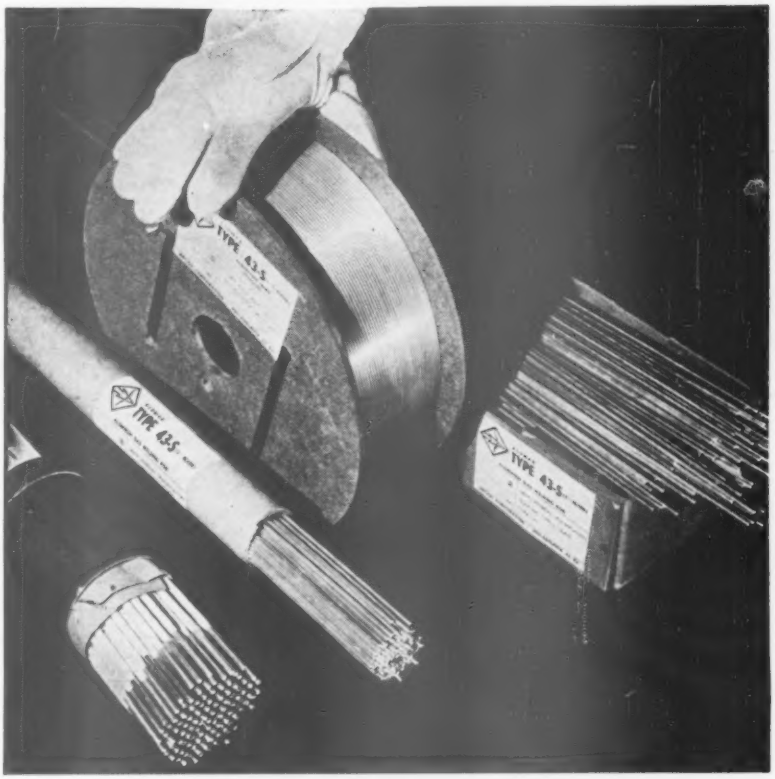

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The survey points out that many new factors have entered the fire safety picture in recent years but, what is more important, is the presence of old fire causes in a more pronounced form. These are large, unprotected areas, the use of woodwork and plastic materials in fabrication processes, as well as the use of flammable liquids.

To receive a copy of this survey, "Fire Hazards in the Metalworking Industries," write to the National Board of Fire Underwriters, Research Department, 85 John St., New York 38, N. Y. If you live in the Middle West, write to 222 W. Adams St., Chicago 6, Ill., and if west of the Rockies, to 465 California St., San Francisco 4, Calif.

Aluminum Data Book

Featuring much new information not found in previous issues, as well as a new die-cut thumb-indexing system, the 1954 edition of *The Aluminum Data Book* has just been issued by Reynolds Metals Co. It offers 220 pages of detailed data on the properties and characteristics of aluminum. . .the most complete and up-to-date source of technical information on aluminum today.

To make this vast collection of information readily available, the book includes a table of contents, a 2-page index of tabular matter and a 20-page itemized cross index with references both to text and tabular information.

A section on fabrication then briefly covers blanking, forming, drawing, spinning, machining, forging, welding, brazing, soldering riveting, and surface finishes.

One portion of the text is devoted to physical properties and the atomic and radioactive properties. Here half life and thermal neutron absorption cross sections are discussed for the first time. Discussions on chemical properties and mechanical properties then follow.

Fabricating characteristics of all the various wrought and cast alloys are condensed in a table which rates them for cold working, gas welding, arc welding, resistance welding, brazing and machining. Minimum recommended bend radii for both 90- and 180-deg cold bending are listed.

The main points of the primary joining methods (welding brazing, soldering, riveting and bolting) are condensed in another table. Finishes for aluminum (20 processes) are detailed in a separate table.

This 220-page, 6- x 8-in. manual is ring-bound to lie flat when open. It will be sent without charge to any engineer, designer, technical man, instructor or executive who may request it on company letterhead. To all others, the price is $1.00 per copy, postpaid. Address all requests to Reynolds Metals Co., Desk PR, 2500 S. Third St., Louisville 1, Ky.

How Amsco® distributor saved eastern coal mine 50 man-hours down time

Eliminated replacement of costly crusher parts

A welding foreman's records, at an eastern coal mine, revealed this startling fact: Coal crusher segments, formerly requiring 75 man-hours for replacement, were recently repaired in 25 man-hours with Amsco hardfacing rod . . . *without removing the segments.* This meant a two-thirds saving in man-hours and elimination of a considerable replacement cost.

Plus this additional important fact: The Amscoated crusher teeth now handle greater tonnage of coal than was previously handled by the original, non-hardsurfaced segments.

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New Air Reduction Catalog

A new condensed 52-page catalog that describes and illustrates all of the Airco products regularly used by job shops, maintenance departments and other users of light welding and cutting equipment, is being offered by Air Reduction.

This catalog covers Airco gases, welding and cutting equipment and accessories—torches, tips, regulators, electrodes, etc. It also includes three of Airco's latest developments—Aircospot (inert-gas spot welding), Easyare 12 electrode and the new heavy-duty cutting attachments for Airco torches.

The catalog is designed to acquaint customers with Airco's line of products, explaining how each item operates and the jobs to which it is best suited. Complete specifications and stock number information is supplied for easy ordering.

For complete information, request a copy of this General Products Catalog, ADC 662B, by writing to Air Reduction Sales Co., 60 E. 42nd St., New York 17, N. Y.

Tungsten Welding Electrodes

The use of argon gas instead of helium is suggested as one method of overcoming the problem of difficult starting or low voltage in a welding operation.

This recommended solution to one of the many problems encountered in a-c and d-c welding is one of several dozen suggestions offered in a new folder now being issued by Sylvania Electric Products, Inc, 1740 Broadway, New York 19, N. Y. The problems described, and their remedies, include difficult starting, brittle electrode tips, excessive heat in electrode or holder, metal pickup, erratic arcs, poor penetration, imprecise welding and others.

The folder, which is based on investigations by the research engineering staffs of Rensselaer Polytechnic Institute and Sylvania's Tungsten and Chemical Division at Towanda, Pa., is available without charge through Sylvania welding distributors. The Tungsten and Chemical Division manufactures thoriated tungsten electrodes and "Zirtung" and "Puretung" electrodes.

Hard-Facing Comparison Chart

A new and comprehensive comparison chart on hard-facing rods and electrodes has just been published by the Mir-O-Col Alloy Co., Inc., 312 N. Avenue 21, Los Angeles 31, Calif.

The chart lists the various rods and electrodes produced by 29 different manu-

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WELDING for ENGINEERS

By HARRY UDIN, *The Massachusetts Institute of Technology;* EDWARD R. FUNK, *Goodyear Aircraft Company;* and JOHN WULFF, *The Massachusetts Institute of Technology*

Treating welding engineering as a field in itself, this book presents a discussion of the fundamental principles and theory underlying the art of welding. The authors help the reader solve many of the practical problems faced in welding by providing a background of basic principles from which a wide variety of problems can be handled.

The principles used, in common with other engineering disciplines, come from the fields of physics, chemistry, mathematics, metallurgy, and mechanical engineering. The treatment of each unit process is presented as soon as possible after its basic principles have been developed. As new elements are absorbed by the reader, more complicated processes are used for illustration. Discussion includes the joining of metals by brazing; gas, atomic hydrogen, and resistance welding; stress concentration and relief; inspection and testing; and design of metallurgical aspects. Whenever possible, an analytical approach is taken.

CONTENTS:

The Welding Processes. Cold Welding. Hot Pressure Welding. Resistance Welding. Metallurgical Reactions in Resistance Welding. Heat and Temperature During Fusion Welding. Permanent-Electrode Arc-Welding Processes. Consumable-Electrode Processes. Welding with Chemical Heat Sources. Metallurgy of Fusion Welding. Transformations. Weldability. Braze Welding. Metallurgy and Mechanics of Brazing. Thermodynamics and Hydromechanics of Brazing. Mechanical Effects Encountered in Welding. Principles of Weld Inspection and Testing.

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A quick-reference guide on

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This handy manual shows you how, when, and where to use over 500 metals and alloys — explains how to select the right metal for part or product, see that it meets specifications, and make sure it stands up under typical conditions. It brings a vast supply of tabulated data on the metallurgical, physical, fabrication, and mechanical properties of metals.

Here is information on AISI steels, ASTM steels, copper, aluminum, tin, magnesium, and scores of other metals and alloys. In a few moments' time it can answer your questions on the strength, hardness, machinability, electrical conductivity, composition, etc., of a given metal ... give you facts taken right from actual tests and industrial practices.

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Edited by Samuel Hoyt

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445 pages, 7½ x 11, $11.00

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Tabulated under each of the metals listed is such information as the chemical composition of the metal, its brittleness, heat treatment, and other characteristics, its industrial uses, treatment temperatures for forging, and annealing, and such technological properties as recrystallization temperature and hot working temperature.

A special feature of the book is the material on end-quench hardenability which shows the relative depths to which various carbon and alloy steels harden.

In addition, there is information on notch toughness, corrosion fatigue, low- and high-temperature properties, and damping, where it is applicable to the metals under consideration.

All of the charts, tables, and data in this book are the result of actual industrial tests and are based on accepted industrial practice. Heretofore such information was available only in scattered literature and reports—now, in this one handy reference, the ASME presents the essential data needed to select the best composition and treatments for producing the properties required in a given metal.

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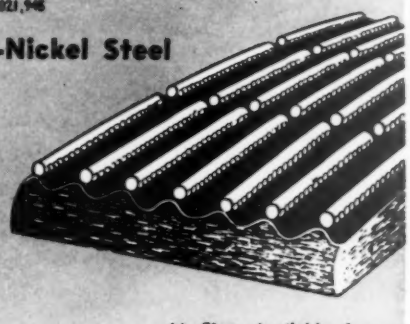

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facturers. It is set up to provide the reader with a quick and easy review of any one particular type hard-facing rod or electrode at a glance.

As a further assistance, abrasion and impact qualities of each type rod as well as many of its applications, are listed for fast reference by the reader. Still another feature of the chart is its listing of individual hardness ratings, both as-deposited and work-hardened, or heat treated as the case may be.

Copies of the new comparison chart are available free of cost or obligation by writing to the Mir-O-Col Alloy Co., Inc., 312 N. Avenue 21, Los Angeles 31, Calif.

Continuous Girders

Iowa State College Experiment Station, Ames, Iowa, has issued Bull. 176 on *Constants for Design of Continuous Girders with Abrupt Changes in Moments of Inertia.*

The main objective of this paper is to present in a handy form the stiffness factors, carry-over factors, and fixed-end moments for beams in which there are abrupt changes in the moment of inertia. The type of change considered is that which occurs when plates are riveted or welded to the flanges of an I-beam over part of its length. The information furnished, however, would apply to beams or girders of any elastic material or materials, provided the change in moment of inertia is a sudden one. The curves of the paper could, for instance, be applied to composite beams of a continuous girder with the moment of inertia changing abruptly at the point of inflection.

Oxy-acetylene in Rolling Mills

A new 12-page booklet on the "Use of Oxyacetylene in Rolling Mills" is now being offered by Air Reduction.

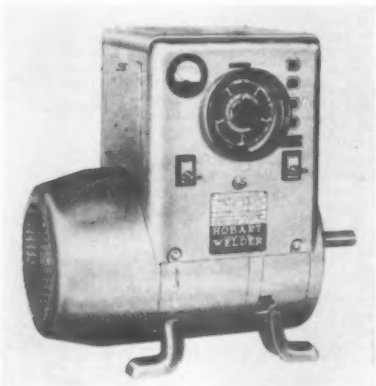
The article reprinted from *Iron and Steel Engineer,* discusses the increase in the uses of oxy-acetylene for economical steel plant operations. It details with charts and photographs the advance of oxygen cutting from routine hand maintenance to engineered scarfing and oxygen hot cut-off machines for standard production jobs. Photographs show an actual installation of a hot cut-off machine in a large Eastern steel mill as well as a scarfing machine layout in this same mill.

For complete details, request a copy of this booklet by writing to Air Reduction Sales Co., 60 E. 42nd St., New York 17, N. Y.

NEW PRODUCTS

Welder-Power Plant

So that farmers, builders, contractors and others who depend upon electric power for many purposes can make use of their own power source and save over the cost of a complete factory built unit, Hobart Brothers Co., Troy, Ohio, is offering the generator only (less engine) of their combination AC Arc Welder and AC Power Plant.



This generator (less engine), which has an ingenious selector panel in conjunction with a standard control panel that changes it from an arc welder to a 110/220 v. power plant and vice versa, can easily be directly coupled to a gasoline engine, or driven from the power take off of a tractor, jeep, truck, etc., with V-belts and grooved pulleys.

When used as an arc welder with the output selector panel in welding position, it makes available 60- to 80-v alternating current, with reactor in circuit to insure excellent welding characteristics. Therefore, you not only get full capacity 200-amp a-c arc welder, but an a-c power unit that will supply sufficient power to operate fifty 100-watt lamps (or their equivalent) regularly or as an emergency "standby" power unit. For complete information write Hobart Brothers Co, Troy, Ohio.

Welding Wire for Sigma or Heliarc Method

Development of a new and improved welding wire for the sigma and Heliarc methods of automatic welding has been announced by Pacific Welding Alloy Co. of Los Angeles.

Trade-named "Spoolalloy," the new wire overcomes many of the shortcomings now present in other existing wires. By special chemical treatment, all oxides are removed from Spoolalloy, thus eliminating the main cause of poor arc and poor fusion.

In addition, Pacific's Spoolalloy is precision wound on specially developed machines. This "tensi-wind" step eliminates the possibility of kinks in the wire and insures a steady smooth flow of wire to the welding head.

Pacific Spoolalloy is available in a wide range of alloys including aluminum, Monel, Inconel, stainless steel, phos-bronze and hi-carbon. It is furnished on expendable spools and is packaged in 25-lb units. Aluminum and aluminum alloy wire are packed on 10-lb spools.

Descriptive literature and price lists on Pacific's Spoolalloy is available on request. Write to Pacific Welding Alloys Mfg. Co., 312 N. Avenue 21, Los Angeles 31, Calif.

Butt Welder Eliminates Defective Welds

Latest models of the Bren/Weld portable band saw blade welder now incorporate a special, patent-applied-for forging action called "Vibra-Forge" which achieves such a secure weld that machinists will be plagued no more by blades broken at the weld.

Heart of the new development is a vibrating mechanism which actuates the Bren/Weld's movable jaw. As the two ends of the saw blade are brought together by the jaws, a hammering or forging action is produced, resulting in a far stronger weld than any heretofore.

The Bren/Weld saw blade welder is a compact, portable unit that butt welds blades up to $^3/_4$-in. and weighs only 35 lb. It operates on 110 v ac, 60 cycles. It has a built-in grinder and a double gage to check thickness of weld on flat saws.

The Bren/Weld unit is manufactured by Brennen, Bucci & Weber, Inc., New York City, while the sales division is Kasson Die & Motor Corp., 32-14 Northern Blvd., Long Island City 1, N. Y.

Aluminum Welding Electrode

To provide maximum weld quality in the inert-gas, shielded-arc welding of aluminum, the Aluminum Company of America has developed a new high-quality welding electrode.

The new consumable electrode, which was produced to achieve weld soundness as required in Navy specifications for this type of product, is expected to set a new standard of quality for inert-gas welding of aluminum.*

The new Alcoa I. G. Welding Electrode was designed to be used in the welding guns employed with existing consumable electrode, shielded arc processes. It can also be used for tungsten-arc welding where the filler wire is fed mechanically to the work.

In the inert gas welding of aluminum, the quality of the electrode used is very critical and is a large factor in producing satisfactory welds. Alcoa manufactures I. G. Welding Electrode specifically to prevent any cause of weld defect from this source.

The new electrode is currently being produced from three aluminum alloys—2S, 43S and A54S.

The electrode conforms with AMERICAN WELDING SOCIETY specification A5.10–54T (tentative 3/17/54) and ASTM specification B285–54T.

Further information on Alcoa I. G. Welding Electrode can be obtained by writing to Aluminum Company of America, 738 Alcoa Building, Pittsburgh 19, Pa.

* Specification MIL-E-16053-B Ships, May 21, 1953.

Low Temperature
EUTECTIC
WELDING ALLOYS

50th year of WELDGINEERING

FOR BETTER SOLUTIONS TO EVERY WELDING PROBLEM

New 1954 DEVELOPMENTS

NITECTIC 222 (DC)
(Pat. Pending)

The first universal electrode for joining all nickel and dissimilar nickel alloys. Weldor need not know specific nickel base metal because this "Low Amp" EutecTrode reduces danger of damage to base metal. NiTectic 222 does not stick or freeze, provides almost 100% slag coverage, eliminates crater cracking. Runs with extremely short arc, may be used even in contact position. Ideal for all nickel overlays. Used on Monel, Inconel, Stellite, nickel irons, stainless steels and many other heat and corrosion-resistant high nickel alloys. Makes possible welding on nickel metals with carbon content too high for previous nickel electrodes.

EUTECTRODE 1850 (AC)
EUTECTRODE 1850 (DC)
(Pat. Pending)

Especially for aluminum bronze—joins 27 different metals and alloys with different expansion coefficients without warpage or stress. 6 times faster than torch bronze brazing. Deposits are 50% harder than bronze brazing, 200% harder than phosphor-bronze, and 15-20% harder than aluminum bronze (ductile type 10). Also available as EutecRod 555 wire for inert gas, shielded-arc welding.

EUTECTRODE 280 (DC)
(Pat. Pending)

"Low Amp" operation and special FrigidArc coating concentrates heat in the weld area—speeds surface alloying, minimizes undesirable base metal dilution. Ideal for phosphor bronze. Coating stabilizes short arc, provides full slag coverage, easy slag removal. Perfect for brass, bronze, copper . . . for "occasional" weldors . . . makes dense, homogeneous welds on dissimilar metals and overlays that are tough and abrasion resistant.

XYRON 2-24 (AC-DC)
(Pat. Pending)

"Cold welds" cast iron in all positions. Saves dismantling and preheating. Deposits are crack-free, dense, machinable, with good color match and high tensile strength. Ideal for shops requiring one versatile cast iron electrode as well as for the occasional cast iron weldor. For alloy cast iron Xyron 2-25 provides highest obtainable machinability.

EUTECTRODE 300 (DC)
(Pat. Pending)

A pure copper electrode with an "AutoThermic" coating that provides its own preheat. By shortening the arc, the weldor can get a high copper content deposit comparable in appearance to an inert gas weld. Works with stable, quiet arc action. Welds have high electrical conductivity.

FOR METALWORKING WITH LESS "WORK"

CUTTRODE #1 (AC-DC) — Oxygenless cutting electrode for all metals (cast iron, carbon and stainless steels, Monel, nickel, aluminum, copper, etc.) Requires no auxiliary equipment. Saves hours of chipping, gouging, scraping, grinding for pennies.

CUTTRODE #2 (AC-DC)—Oxygenless UNDER-WATER cutting electrode.

CHAMFERTRODE (DC) — Chamfers and gouges all metals with electric arc. No oxygen required. Unusually fast removal of excess metal, old weld metal, preparing sections for welding, routing out unwanted sections. On many jobs provides enough "preheat" for immediate "non-fusion" welding — saves preheat time.

THERMOTRODE (DC) — The fastest known means of pre-and-post heating with electric arc. No oxygen or auxiliary equipment required.

from the pioneers in CONTACT ELECTRODES

HAND-O-MATIC #1 (AC-DC) — The original contact electrode introduced in America by Eutectic. Hand-O-Matic anti-fatigue contact electrodes have been copied but never equalled. Best as an all-position electrode on thin gauge, mild steel welding.

NEW HAND-O-MATIC #2 (AC-DC) — The first mild steel electrode with automatic slag removal. Greatly reduces welding time, finishing costs. Can be used on a wider variety of light gauge base metals, than conventional electrodes due to new coating and lower heat input.

THE 27 MOST WIDELY USED EUTECTIC WELDING ALLOYS

to replace conventional materials

FOR CAST IRON JOBS

EUTECROD #115* (Torch) — An amazingly "cold filler" (354°-600°F.) for sealing cracks, defects; for emergency repairs on cast iron. (Patented)

EUTECROD #142FC* (Torch) — Ensures high strength, machinable, color-matching deposits on gray and alloy cast iron. (Patented)

EUTECROD #146FC* — Low cost bronze type alloy for all jobs on cast iron, steel, brass, bronze, copper, malleable iron, galvanized.

XYRON #2-24 (the new, improved EutecTrode #24)—"Low Amp" electrode for cold welding cast iron without preheating or dismantling. (Pat. Pending)

EUTECTRODE #25 (AC-DC) — High strength, machinable electrode for troublesome alloy cast iron. (Pat. Pend.)

EUTECTRODE #27 (AC-DC) — "Low Amp" cast iron electrode for non-machinable deposits.

FOR STEEL JOBS

EUTECROD #16FC* (Torch) — Highest strength "thin-flowing" patented alloy for all steels. (Patented)

EUTECROD #1800* (Torch) — High silver content, cadmium free alloy with exceptional capillary flow. Ideal for extremely low heat joining of closely fitted steels, copper, and nickel alloys.

EUTECROD #1601* (Torch) — Highest strength silver-content alloy for joining carbide tips; for production joining parts of very light gauge metals.

EUTECTRODE #68(AC) — 680(DC) — Toughest electrode made for joining all high alloy steels. (Patented)

STEELTECTIC (AC-DC) — "Universal" steel electrode welds without slag interference. (Patented)

HAND-O-MATIC (AC-DC) — High speed production, contact-type, no-gap mild steel electrode.

EUTECTRODE #600 (DC) — Machinable "Low Amp" electrode for welding sheet metal in all positions.

FOR ALUMINUM JOBS

EUTECROD #190* (Torch) — For high strength joints on thin aluminum alloys. (For "poor fit" use EutecRod #21*).

EUTECTRODE #2101 (DC) — First easy-to-control, maximum strength electrode for cast and wrought aluminum. (Pat.)

METAL WORKING ELECTRODES

CUTTRODE (AC-DC) — Cutting-piercing electrode "slices" metal without air or oxygen. (Pat. Pending)

CHAMFERTRODE (DC) — Chamfering-grooving electrode blasts away unwanted metal without air or oxygen. (Pat. Pending)

THERMOTRODE (DC) — For localized heating and preheating . . . all three without supplementary air or oxygen or special equipment of any kind. (Pat. Pending)

FOR COPPER, BRASS, BRONZE SALVAGING JOBS

EUTECROD #1801* (Torch) — "High Silver," thin-flowing alloy for steels and non-ferrous metals.

EUTECROD #185FC* (Torch) — Dual-purpose bead forming alloy for joining and for machinable overlays. (Patented)

EUTECROD #800* (Torch) — Thin-flowing alloy for copper, brass and bronze. (Patented)

EUTECROD #180* — For high strength joints on thin-walled and intricate copper and copper alloy parts.

EUTECROD #18FC* (Torch) — Low melting, high strength universal alloy for dense, homogeneous bonds on steel, galvanized sheet, brass, bronze and copper alloys.

FOR WEAR, ABRASION, BUILDING UP, IMPACT, CORROSION

EUTECTRODE #2 (AC-DC) — For economical wear, and abrasion-resistant overlays on all steels.

EUTECTRODE #2B (AC-DC) — For machinable overlays and welds to resist abrasion and impact on all ferrous metals.

EUTECTRODE #10 (AC-DC) — "Low Amp" electrode for super-hard, abrasion-resistant overlays.

EUTECROD #11FC*—Hard overlay with maximum wear resistance for oxy-acetylene torch welding on ferrous metals.

*For best results, use with corresponding special Eutector® Superflux

In more than 78,000 American welding shops . . . and many more throughout the world, Eutectic Low Temperature Welding Alloys are used and preferred. This preference is the result of Weldgineering . . . the constant development and improvement of "Low Temp" EutecRods (gas) and "Low Amp" Eutec-Trodes (arc) to cut welding time, improve welding quality and lower welding cost. Weldgineering is just one more reason why you can rely on Eutectic . . . "America's Leading Institution Devoted to the Research and Manufacture of Specialized Metal-Joining Alloys" . . . for solutions to your welding problems. The alloys described here, or many others not shown, can solve your welding problems too . . .

FOR EASIER SOLDERING

EUTEC-TINWELD — Original solder-paste-flux "paint-on" compound. For easy, one step soldering-tinning of all metals (except white metals). Superior to ordinary lead-tin solders in 6 money-saving ways. Available in 2 and 5 lb. tins in four formulations — regular, lead-free, neutral, refrigeration.

NEW EUTEC-COPWELD — "TinWeld" style compound for copper and copper alloys. Eliminates costly solder rings and shims. Greatly simplifies induction and resistance welding. Saves pre-placement time. Good conductivity and corrosion resistance. In 20 oz. cans.

NEW ALUTIN #51 — Lowest melting flux-containing alloy for bonding all metals including aluminum. Perfect for hard-to-wet metals. For all heating methods. Simplifies joining all metals, filling voids, building up fillets. Handy 5 lb. "Protecto-Spool."

FOR LONGER LASTING OVERLAYS WITHOUT WARPING

EUTECHROM #2 (AC-DC). For low-cost abrasion and mild impact resistance. Features exclusive electrode coating which, like all Eutectic overlay materials, ensures bonding at lowest possible heat.

EUTECHROM #10 (AC-DC). For resistance to severest types of abrasive wear. Hardness at red heat far superior to ordinary electrodes which become soft at same temperature.

EUTECTRODE 68 (AC), 680 (DC). Very high alloy steel overlay electrode, unsurpassed for tool and die salvage. A "must" for every shop needing high quality maintenance and salvage.

EUTECROD 185 FC (torch). Welding's most advanced rod over bronze welding for machinable overlays. Harder, tougher, easier to apply than conventional bronze rods. (use with Eutector Flux 185)

FRIX. The most economical overlay material available. Provides wear expectancy three times that of phos-bronze materials.

INSTANT HARDNER #75. The only cyanide-free easy-to-use hardening compound for small tools and parts without heat treating.

KROMOLAY 6900. For skin-thin preventive maintenance overlaying of new and used steel parts. High wear, corrosion, heat resistance.

Eutectic, a specialist in the hard overlay field, also offers improved EutecRods and EutecTrodes for high speed steel — EutecTrode 5HSS-FC (torch), EutecTrode 6HSS (AC-DC).

November 1st to Novembe[illegible]th

WELC[illegible]

November 1st to November 5th

WELCOME

to Eutectic's idea exchange reception suite during the National Metal Exposition in Chicago. See us at the Sherman Hotel . . . enjoy refreshments with us . . . relax and review welding's progress.

START YOUR WELDING SAVINGS

WITH THESE HANDY KITS

HANDY, ECONOMICAL WALL PACKS—ONLY $29.50

Liberal introductory quantities of most-used EutecRods and/or EutecTrodes for all common metals, jobs. Priced at 25-lb. rate, shipped in metal wall cabinet with complete instructions. Ideal "small shop" selection for the "occasional" welder and solderer. Assortment for gas and/or arc welders.

WORK SAVING CHEMICAL AIDS KIT — ONLY $9.95

A generous supply of pre/post cleaners, "EutectoMask," "Form-A-Jig," Cyanide-free Instant Hardener #75, "Mark-A Cut" Pencil, Kromolay 6900 quick overlaying compound and standard size can of Eutec-TinWeld — the time and labor saving new solder-paste-flux compound.

NEW! EUTECTOR FLUX KIT — ONLY $9.95

An ample assortment of famous Eutector Fluxes (6 universal, 3 aluminum, 2 cast iron, 1 magnesium). All with four important advantages over commercial fluxes — (1) Indicate correct welding temperature automatically, (2) Automatically clean the work, (3) Promote bonding action, (4) Encourage alloy flow — make "a little alloy go a long way."

POPULAR SOLDERING KIT — ONLY $9.95

Standard introductory packages of 4 Eutec-TinWeld compounds, AluTin No. 51 (for aluminum, hard-to-wet metals), EutecRod 115 (for cast iron), EutecRod 152 (low-melting, lead-free solder-type alloy for copper and steels), plus companion Eutector Fluxes. Convenient storage kit with every unique Eutectic solder-replacing product needed for "occasional" repairs on all metals. For all heating methods.

(Helpful, complete instructions accompany each WALL PACK and KIT).

HERE'S WHERE YOU Clip YOUR WELDING COSTS

EUTECTIC WELDING ALLOYS — EUTECTIC WELDING ALLOYS CORP. 40-40 172 Street, Flushing 58, N. Y.

OK Eutectic, show me, without obligation on my part, how your "Low Temperature Welding Alloys" can make my welding "Better, Faster and Cheaper". I'm interested in "non-fusion" welding of (name parts, base metals, etc.)

SEND ME YOUR FREE TECHNICAL DATA ON MODERN WELDING PROCEDURES FOR

(circle the metals you are interested in)

Cast Iron — Steel — Stainless Steel — Aluminum — Copper — Nickel — Brass — Bronze — Magnesium — Zinc Die Casting

I want to start saving with "non-fusion" procedures NOW — so send me the following kits —

- ☐ WALL PACK #1 (for Arc Welders $29.50)
- ☐ WALL PACK #2 (for Gas Welders $29.50)
- ☐ WALL PACK #3 (for Arc and Gas Welders $29.50)
- ☐ SOLDERING KIT @ $9.95
- ☐ CHEMICAL AIDS KIT @ $9.95
- ☐ FLUX KIT @ $9.95

☐ CHECK ENCLOSED (Eutectic pays postage) ☐ BILL ME ☐ BILL MY COMPANY

NAME_____

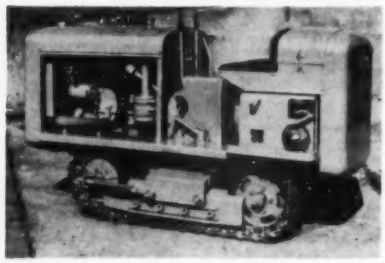
COMPANY NAME_____

COMPANY ADDRESS_____

CITY_____ ZONE____ STATE_____

Self-Propelled Welder

To offset the difficulty of getting a welder to the place where it is needed, Schramm, Inc., West Chester, Pa., has mounted a 300-amp gasoline-engine-driven welder in a self-propelled crawler. Power from the engine is transmitted to the tracks through a chain, a differential and



final bull gear drive. Steering is accomplished by brakes on the drive wheels. This gives the ability to turn the machine on its own center, a real advantage when getting into inaccessible places. The total over-all width is less than 32 in. Four forward and one reverse speed are provided. Electric starting is standard equipment.

New Tempilaq°

Tempilaq° for 425 and 475° F has been added by Tempil° Corp., 132 W. 22nd St., New York 11, N. Y., to their line of temperature-indicating materials. Tempilaq° is now available in the range 113 to 400° F in 12½-deg intervals, in the range 400 to 550 F in 25-deg steps, and in 50-deg intervals from 550 to 2000° F—each indicating its specific temperature rating with an accuracy of ±1%.

Tempilaq° consists of materials of calibrated melting points suspended in an inert, volatile, inflammable vehicle. On application, it dries quickly, leaving a mat opaque coating which liquefies when the specified temperature rating is reached.

Moly-Mang Hard-Facing Electrode

A new line of electrodes, the Mir-O-Col Moly-Mang, has been placed on the market by the Mir-O-Col Alloy Co., Inc., Los Angeles, Calif.

An excellent rod for build-up work, the Moly-Mang produces an extremely high-tensile strength making it highly desirable for many applications including frogs and switches. It is especially recommended for build-up work on manganese castings.

Hardness of deposit is 5 to 10 Rockwell C scale and will work harden to 50 Rockwell C when subjected to peening or impact. Application is by a-c, d-c electric arc with reverse polarity.

Moly-Mang is available in a full range of sizes and is packaged in hermetically sealed metal containers to prevent moisture pick-up and rod scuffing. Descriptive literature on the new Moly-Mang electrode, along with free samples, are available upon request. Write to Mir-O-Col Alloy Co., Inc., 312 N. Avenue 21, Los Angeles 31, Calif.

New Method Simplifies Welding

A new method of welding that eliminates skills normally required, and claimed to be as easy as turning on a light switch, promises to make it possible for the rapidly growing number of home fix-it-yourself and hobby craftsmen to work with metals as readily as with wood. It is expected that the method will also be useful to business and service estadlishments such as bakeries, hotels, bottling plants, hospitals, body shops, repair shops and other users of metal equipment and machinery that occasionally need a quick, easy method of repair or maintenance fabrication.

The Lincoln Electric Co. of Cleveland, Ohio, has developed the new method, called Selfweld, to create a quick, foolproof method, usable by everyone, of joining metals for repairing and making such things as metal furniture, household and business equipment, tools, toys and automobiles. Lincoln has also developed a new 100-amp welding machine for use with Selfweld. The machine, complete

Aronson supplies the Welding Industry with the ONLY complete line of *Quality* Positioning Equipment.

POSITIONERS

UNIVERSAL BALANCE POSITIONERS for Instant manual Positioning.
27 models of BENCH TURNTABLE Automatic Welding Positioners.
PRECISION GEAR DRIVEN Magnetic Brake Positioners.
Fully Automatic MODEL 21 and X21 SERIES of Gear Driven Positioners.
HEAD and TAIL STOCK Positioners . . . Rugged . . . Precise.
Steady, Positive, Precision Rotation with TRACTRED TURNING ROLLS.
Heavy-Duty "Overload Protected" RUBBER TIRED TURNING ROLLS.
Rugged DRIVER and IDLER CARS for Turning Roll mounting.
FLOOR TURNTABLE Positioners with adjustable base.
MAGNETIC POSITIONING CLAMPS with Permanent Magnet Core.

Visit our Booth at the National Metal Exposition at Chicago, Nov. 1-5.

Aronson MACHINE CO. ARCADE, N. Y.

Production Up 40%
Fuel Costs Down 80%
Sections of "track roller shaft" before welding
"Track roller shaft" after TOCCO Induction Welding

with TOCCO* Induction Welding

Here's the story of how one company, a large manufacturer of automotive equipment and farm implements, is using TOCCO Induction Heating to increase production and effect substantial savings at the same time.

Production Increased

When TOCCO Induction Heating replaced oxy-acetylene, output of these hollow "track roller shafts" went up from 220 to 300 pieces per 8 hour shift. The heating cycle with TOCCO is only 55 seconds as opposed to 90 seconds formerly required with gas. Result: much lower labor cost per unit.

Fuel Savings

Fuel costs nosedived from $10.50 per hundred pieces to only $1.95—about $25 per shift saved on fuel costs alone. Other important savings have resulted from a substantial reduction in down time and maintenance costs. Quality of the weld is more uniform with Induction, and hazards of explosion present with former method are eliminated.

If the manufacture of your product involves welding, heat treating, forging, brazing or the melting of ferrous or non-ferrous metals, don't overlook TOCCO as a sound method of increasing production, improving product quality and slashing costs.

THE OHIO CRANKSHAFT COMPANY

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FREE BULLETIN

THE OHIO CRANKSHAFT CO.
Dept X-10, Cleveland 1, Ohio

Please send copy of "TOCCO Induction Heating."

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Position_____

Company_____

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City_____ Zone____ State____

Look Ma, no hands—Welding without touching his work, this amateur welder is using a new Selfwelding method to make a piece of iron furniture

with electrodes, Selfweld holder and accessories, costs less than $100.

Selfwelding is said to eliminate the difficulties that would be encountered normally by the amateur in learning the skill of manipulating the welding electrode and controlling the arc. The new method employs a special welding electrode and special electrode holder. To make a weld, the tip of the electrode is simply held against the metals to be joined at the point where the weld begins, a switch on the holder is pressed to fire the electrode, and the electrode, as the tip is held against the metal, automatically makes the weld itself. The electrode and holder normally do the work required of the person welding. Locating the beginning of the weld, starting the arc, feeding the electrode, the electrode angle and the travel speed are controlled automatically by the design of the electrode and holder. A supporting leg on the holder can be used to help locate and steady the electrode on the joint and to control the angle of the electrode. The coating of the electrode touches the work at all times so that the arc length is automatically determined. The melt-off rate automatically controls welding speed. Excellent welds are made on the first try, it is claimed.

The new 100-amp welding machine Lincoln has introduced for use with Selfweld is called the Lincwelder 100. It can be operated safely on the properly fused electrical circuit of the average home or business establishment, either 115 or 230 v. The new method can also be used with welding equipment of the types already in operation.

Sanitizing of Goggles and Respirators

The Chicago Eye Shield Co. has just announced its new concentrate which mixes instantly with water to form an effective disinfectant for sanitizing all types of safety glasses, goggles, and respirators which are not harmed by water itself. The CESCO Disinfectant Concentrate is *nonirritating* to the skin and *nontoxic* in normal use.* It is registered under Section 4 of the Federal Insecticide, Fungicide and Rodenticide Act.

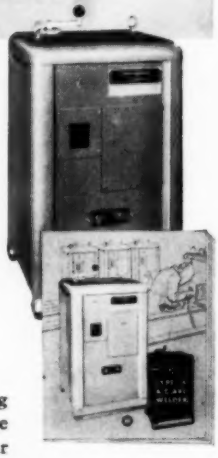
After sanitizing in a solution of CESCO Concentrate, articles need not be rinsed, washed off or wiped dry. Best results are obtained by simple air-drying of the items, after which they are safe and ready for reuse.

Further information may be obtained from Chicago Eye Shield Co., 2300 Warren Blvd., Chicago 12, Ill.

Double-Duty Blowpipe

A lightweight, fully portable oxy-acetylene outfit in the low-price range has been introduced by Linde Air Products Co., a Division of Union Carbide and Carbon Corp. The new unit, for light-to-medium welding and cutting work in auto repair shops, welding and sheet metal shops, and industrial plants, is called the Prest-O-Lite Welding and Cutting Outfit, and features an exclusive "all-in-one" blowpipe with interchangeable welding and cutting tips. The same blowpipe heats, bends, solders, brazes, welds and cuts. No special attachments are needed. As

GET THIS NEW WESTINGHOUSE "TA" WELDER BOOKLET FREE



The Westinghouse "TA" Welder is completely new! And it's loaded with the most sensational line-up of welding developments yet introduced in one a-c arc welder.

CHECK THESE PLUS FEATURES

Thermal Overload Protection...Hot-Start . . . Single-Range Current Control . . . Weatherized Construction . . . more compact . . . light weight and wider operating range.

WANT PROOF?

See your nearest Westinghouse Welding Distributor for your copy of the 16-page book on the new "TA" and ask him for an actual demonstration, or write Westinghouse Electric Corporation, P. O. Box 868, Pittsburgh 30, Pa. J-21853

YOU CAN BE SURE...IF IT'S Westinghouse

Buy "PROVEN FLUXES"

Years of GUARANTEED SATISFACTION behind these GOOD

"ANTI-BORAX" FLUXES

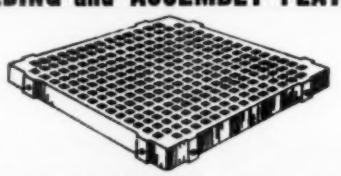
Insist on them—Unequalled Quality

No. 1 Cast Iron Welding Flux
No. 2 Brazing Flux for Brass, Bronze, Steel, etc.
No. 4 Braz-Cast Flux for Bronze Welding Cast Iron
No. 5 & 8 Cast & Sheet Aluminum Fluxes
No. 9 Stainless Steel Welding Flux
No. 11 Tinning Compound
No. 16 Silver Solder Paste Flux

Mfg. By

ANTI-BORAX COMPOUND CO., INC.
Fort Wayne, Ind.

WELDING and ASSEMBLY PLATENS

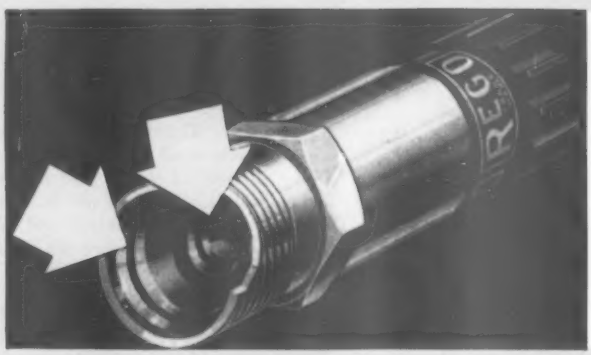


Floor plates — bending tables — layout tables — straightening tables — dog blocks — bending blocks — blacksmith blocks. 5'x5' — 6'x6' — 6'x8' — 6'x10' — 5'x10' — 6'x12' — 3'x3' — either 6" or 7" thick.

STAHL EQUIPMENT CO.
94 Washington St., Brookline Village 46, Mass.

Now, change tips with a twist of the wrist...

with the REGO* "GX" welding torch



THIS CUT-AWAY shows seating rings (arrows) in conical seating surfaces of the REGO "GX" head. Made of extra tough, long-wearing Neoprene, they assure a perfect gas-tight coupling of tip, mixer and head . . . are easily and quickly replaceable when necessary.

New Neoprene Seating Rings make hand-tightened joints leakproof... reduce maintenance costs... lengthen torch life

You don't need a wrench to change tips on the new REGO "GX" Welding Torch. Thanks to Neoprene seating rings in the torch head, you get positive, leakproof coupling of tip, mixer and handle . . . *with hand-tightening alone.*

There's no metal-to-metal contact . . . no strain on threads . . . no chance of damage to vital seating surfaces, even in dusty or sandy atmospheres. And because the seating rings absorb all normal wear and abuse, today's "GX" will last longer, torch head will never require costly re-seating.

Neoprene seating rings are just one of many sound reasons why the REGO "GX" continues to be your best buy in an all-purpose welding torch. Ask to see it now at your nearest NCG branch or authorized NCG dealer.

REGO "KXA" CUTTING ATTACHMENT

Doubles the usefulness of the REGO "GX" Welding Torch. Couples to the "GX" handle with a twist of the wrist to make an efficient cutting torch with capacity to 8-inch or greater thicknesses in steel. Available with either 75° or 90° bronze head.

*T. M. of the B. B. Co.

NATIONAL CYLINDER GAS COMPANY

840 N. MICHIGAN AVENUE • CHICAGO 11, ILLINOIS

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NCG
EVERYTHING FOR WELDING

FOR OXY-ACETYLENE WELDING AND CUTTING

There is a Dockson Better-Built Torch for all your jobs. Dockson Torches incorporate a new, longer life, better seal compound developed especially for oxy-acetylene service in both the mixer and union rings. Dockson's two-ring construction means fewer rings to replace, stronger construction, prevention of possible breakthrough.

Your DOCKSON DISTRIBUTOR—a selected specialist, stocks a complete line of Dockson products to give you fast service and personal attention. We back our distributors 100%.

WRITE FOR YOUR DISTRIBUTOR'S NAME AND COMPLETE CATALOG OF WELDING AND CUTTING EQUIPMENT.

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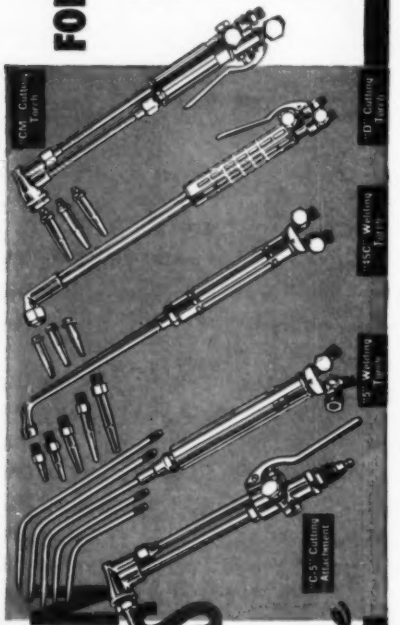
3239 WABASH • DETROIT 8, MICH.



DOCKSON TORCHES
Built for Better Service

New "All-in-One" Oxy-acetylene Outfit

furnished, the outfit welds up to 3/16 in., and cuts through 3/8 in. of solid steel. Additional tips are available for welding up to 3/8 in. and cutting up to 2 in.

The new Prest-O-Lite outfit comes complete, with full instructions. Besides the double-duty blowpipe, it includes one cutting and three welding tips, oxygen and acetylene pressure regulators, fitted double hose, a friction lighter, goggles and wrench.

This handy outfit is the perfect tool for auto repair shops, garages, job welding shops—wherever average day-to-day heating, bending, soldering, brazing, welding and cutting work is done. Compact and easy to use, the Prest-O-Lite Welding and Cutting Outfit is also ideally suited for on-the-spot equipment repairs and low-cost maintenance work on the farm and in industrial plants.

Clamps

"Low silhouette" and "complete clearance" are the two big features of the new Destaco Model 507 Toggle Clamps which have just been brought out by Detroit Stamping Co., Detroit, Mich.

Specially designed to "hug the fixture" and with a "flop-over action" which flicks the spindle and holding bar completely away from the working surface, the low silhouette of these Destaco's brings new ease and convenience of work insertion and removal.

The 507's come in two models—507-U and 507-S. The 507–U's feature the U-bar which is recommended as excellent for adapting various spindles for proper work contact, especially for those who do not have welding facilities. Several Destaco Spindles may easily be mounted in this U-bar.

The 507-S's are so designated because they have the solid carbon-steel holding bar instead of the U-bar. These 507-S's come with a positionable bolt retainer which may be welded to the bar at any desired angle. This model is recommended as ideal for holding sheets or strips of metal during welding, drilling and other such processing and assembly operations—and for holding sheets of plastic during laminating, cementing, vacuum-drawing and other similar manufacturing operations.

Detroit Stamping Co., 350 Midland Ave., Detroit 3, Mich.

Low-Cost Resistance Welder

A new, low-cost, 1 kva, small parts resistance welder with dual heads that can be quickly and independently adjusted for pressure, time and heat in progressive assembly work has recently been developed by Royson Engineering, Hatboro, Pa. The electrodes and holders are adjustable in all directions permitting a wide variety of setups and the unit, sold as a complete package containing welding heads, timers, controls and transformer in a specially constructed cabinet, handles strip and wires up to 1/32 in.

Air-cooled, 1/8- or 3/32-in. electrodes are used which maintain constant pressure on the work regardless of pedal movement and force. The electronic timers use cold cathode thyratrons for long, trouble-free service and the tube is active only during the actual welding cycle. A knob at the front of the cabinet permits fine adjustment of heat. Welding current on the Royson welder passes through electrodes and holders only and not through castings or any other parts. Two foot pedals and chains are included in the

price and special holders and fixtures can be provided. The unit operates from any conventional 220–v, 60-cycle, single-phase outlet.

For additional details, write Royson Engineering, Hatboro, Pa.

Welding Table

A unique, new welding table has just been introduced by the Papec Machine Co., Shortsville, N. Y. Known as the "Vent-A-Weld" table, it provides a large, rugged work surface and at the same time draws out and exhausts to the outer air all smoke and fumes from the welding operation. If desired, Vent-A-Weld can be connected to an electrostatic filter, thus conserving heat where state laws permit re-use of filtered air.

By exausting the smoke and fumes Vent-A-Weld improves visibility for the operator and reduces operator fatigue. The better operator efficiency results in greater production which helps to pay the cost of the table in a short time.

Vent-A-Weld is sold through distributors or direct from the factory where no distributor is available.

"Junior" Soldering Gun

Weller Electric Corp., Easton, Pa., has introduced a new low-cost Junior Soldering Gun with ample power for all general soldering. Designated Junior Model 8100, the new gun incorporates many of the features found in the larger models and is ideally suited to the role of second soldering gun in the maintenance or craftsman's tool kit. It is rugged enough to withstand the impact of other tools, yet light enough to be easily portable for service calls and on-the-spot repairs.

Instant heat at a power rating in excess of 100 watts is ample for practically every type of general soldering job.

For additional information, write Joseph F. Whitaker, Weller Electric Corp., 808 Packer St., Easton, Pa.

Rectifier-Type Welder

A new 300-amp, NEMA-rated, rectifier-type welder, featuring quiet operation and low maintenance cost, has been announced by the General Electric Co.'s Welding Department.

Now in production at the department's new plant at York, Pa., the welder offers full time arc force control for holding very short arcs with deep penetration, according to company engineers.

A current range of 20 to 375 amp is provided. The new welder utilizes the moving primary coil design, obtaining current adjustments by separation of primary and secondary coils. Stepless current control and highly accurate amperage settings are made possible by this design. Windings are aluminum and silicone insulation is used on all coils.

Offered as optional equipment, the fully automatic arc force control provides an extra surge of current to blast away short circuiting metal drops which would otherwise freeze a short arc and cause sticking. The arc force control will operate continuously with little danger of cutting out on critical applications, making the rectifier welder ideal for difficult work such as pipeline root passes, vertical welding, low-hydrogen electrode jobs and others where a short arc and deep penetration are required, the engineers said.

Cooling for coils and rectifier stacks is provided by forced-draft ventilating fans. Operating on the updraft principle the fan can be reversed by spring loaded toggle switch to blow dust from the stacks, prolonging their life.

A polarity reversing switch is standard equipment and access for maintenance is simplified due to the unit's removable side covers.

Designated 6WR30B, the new welder is available for 220/440 or 550 v operation.

Descriptive publication GEC-1267 describes the G-E development.

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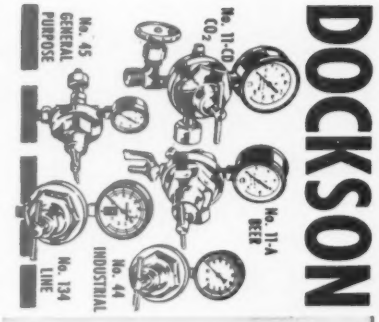

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abstracts of CURRENT WELDING PATENTS

prepared by Vern L. Oldham

Printed copies of patents may be obtained for 25¢ from the Commissioner of Patents, Washington 25, D. C.

2,684,603—Pressure Welding Apparatus—Harry E. Schonberg, Indianapolis, Ind., assignor, by mesne assignments, to Union Carbide & Carbon Corp., a corporation of New York.

This patent relates to butt welding hollow members together and includes mechanism for aligning the members with a portion of each of the opposing surfaces in abutting relation, and means are provided for applying welding heat to each of the members at and adjacent the abutting surfaces. Other means force the abutting surfaces together and produce a ridge of metal that has been softened and upset by the welding heat. The aligning mechanism includes a combined aligning and sizing device including an annular ironing die having a surface for contacting the outer peripheral surface of each member and other means are provided for moving the aligning mechanism along the members in a path which includes the zone of the upset metal. The aligning mechanism and the welding heat applying means are moved as a unit into and out of operative position relative to the metal members being welded together.

2,685,017—Apparatus for Welding Under Pressure Studs or Bolts to a Curved or Plane Surface—Bror G. A. Anderson and Nils Wallenborn, Stockholm, Sweden, assignors to Allmanna Svenska Elektriska Aktiebolaget, Vasteras, Sweden, a corporation of Sweden.

The patented apparatus is adapted to butt weld metal studs formed from wire material to a workpiece. The apparatus includes combination sizing and cutting means for straightening the wire and advancing it toward the workpiece, as well as to cut the wire into lengths to form studs. Welding jaws are provided for applying part of the welding pressure to the studs and for supplying welding current thereto, while an abutment is present in the sizing and cutting means for engaging the stud to prevent it from sliding from between the welding jaws during welding action.

2,685,628—Electric Resistance Welding Machine—Samuel Hunter Gordon, Charles Thomson and Robert Fulton Johnstone, Inverness, Scotland, assignors to Resistance Welders Ltd., Inverness, Scotland.

This patent relates to an automatic flash-butt resistance welding machine including a fixed head, a moving head and liquid pressure means to move the moving head toward the fixed head to effect flashing and butting of workpieces mounted on the heads. Improved liquid pressure means are provided that have first and second liquid-pressure-producing units providing, respectively, lower and higher liquid pressures. Operator controlled means control the first pressure-producing unit, and means actuated by the moving head control the second pressure-producing unit with the first pressure producing unit being rendered operative by the operator controlled means to move the moving head during flashing of the workpieces. The means actuated by the moving head are actuated at the termination of the flashing period to bring the second pressure-producing means into operation and apply pressure to the moving head to effect butting of the workpieces.

2,685,629—Tube Welding Mechanism—Cecil C. Peck, Euclid, Ohio.

In this patent, a tube welding mechanism is disclosed that includes a cradle for receiving a cylindrical workpiece having a longitudinal seam to be welded, and an automatic electric arc-welding head mounted to traverse and weld this seam. Other means are covered in the patent that relate to clamping members adapted to engage the workpiece on both the inside and outside thereof adjacent the seam to be produced therein for securing the workpiece in position during welding action thereon.

2,685,630—Welding System—Harold J. Graham, Highland Park, Mich., assignor to Graham Manufacturing Corp., Detroit, Mich., a corporation of Michigan.

Graham's patent relates to a method including the steps of shaping one end of a welding stud or wire to a point and contacting such point with a surface to which the welding stud is to be welded. Thereafter a current is sent through the stud and the surface while applying to the stud a percussive blow, which current initially melts the material of the contact area and separates the point from the surface to form an arc whereupon the blow joins the end to the surface.

2,685,631—Gas Shielded Arc Welding Torch—Arthur P. Scheller, Chatham, N. J., assignor to Union Carbide and Carbon Corp., a corporation of New York.

This patent relates to a gas-shielded arc-welding torch, including an insulation-covered hollow metal current and gas supplying head, an electrode holder detachably connected to the head in gastight and electrically conducting relation thereto and a collect slidably inserted into the electrode holder and clamped between the head and holder to grip an electrode. The patent discloses specific details of the remainder of the construction of the torch.

2,685,632—Gas Blanketed Arc Welding Torch—Edward R. Behnke, Parsippany, Arthur P. Scheller, Chatham, and Frank J. Pilia, West Orange, N. J., assignors to Union Carbide and Carbon Corp., a corporation of New York.

A specialized type of a welding torch is disclosed by this patent. The torch is of a quick take-apart, liquid-cooled construction and with the torch being adapted to be used with a gas-shielded welding arc.

2,686,134—Coating of Welding Rod—Walter H. Wooding, Yeadon, and Charles T. Gayley, Lansdowne, Pa.

This patent relates to a method of fabricating a coated welding rod and includes the step of forming a composition including flux-forming and slag-forming ingredients, an alkali silicate, water and between 0.5% to 4.0% of lithium borate. The melting points of some of the slag-forming ingredients are higher than the melting point of the borate. A weld rod is coated with this composition and thereafter such coating is sintered.

2,686,860—Inert Gas-Shielded Arc Welding Torch—Mortimer P. Buck, Westfield, N. J., and Cecil Franklin Crumbley and Ernest Frederick Leaberry, Huntington, W. Va., assignors to International Nickel Co., Inc., New York, N. Y., a corporation of Delaware.

This patent covers a shielded electric arc welding process comprising striking an arc between an electrode and the work to provide a weld zone and directing a laminar annular stream of helium gas surround-

Better Welding!

ONE TOUGH JOB
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Improved non-synchronous performance with Square D's NEW SLOPE CONTROL

Heat—
Up & Down
Slope

BETTER AND MORE PROJECTION WELDS through more uniform distribution of welding current.

PERMITS WELDING NON-FERROUS METALS. Reduced "spitting" at electrodes improves appearance of aluminum and other non-ferrous welds—extends electrode life.

DESIGN FEATURES

Matched Enclosures. Slope Control enclosure matches Square D Non-Synchronous Welder Controller (Nema N2), shown at right. Also matches individual Square D welding timer or contactor enclosures.

Simplified Circuit, standard components, and heavy-duty construction.

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SMALLER, SOLID COPPER CLAMPS
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ing the electrode and to blanket the metal in the weld zone. A secondary laminar annular hydrogen gas stream is directed so as to envelop the helium gas stream with the hydrogen gas stream converging with the helium stream at an angle such that no appreciable admixing of the hydrogen and helium occurs in the arc zone. Thus protection is provided against air contamination of the helium gas to eliminate, substantially, oxidation of the weld metal and resulting high porosity.

2,687,464—High-Frequency Induction Tube Welding—Thomas J. Crawford, Berkley, Mich.

Crawford's patent relates to a method of producing welded tubing and includes the steps of forming a generally tubular blank having a longitudinally extending open seam, and generating a high-frequency alternating magnetic field through which the tubular blank is passed, such field being substantially uniform circumferentially of the blank. The opposed seam edges are brought together at a point beyond the effective limits of the magnetic field, the point is spaced a sufficient distance beyond the limits in the direction of travel of the blank that the induced voltage across the spaced seam edges will be substantially lower immediately prior to the point than within the region to cause a high-frequency induced current to flow generally circumferentially of the blank within the field and along the opposed seam edges to the point of juncture thereof. The combined result of the skin effect and proximity effect concentrates the current along the seam edges to an increasing degree toward the point of juncture where an extremely high current density is obtained and heats the seam edges to fusion temperature to interfuse the same.

NEW 150' WELDREEL
Welding Hose Reel

Now you can store and handle 150 feet of double welding hose on a Weldreel — with the new Model OAB. The new big reel gives you all the safety and convenience of the 50-foot Model OA and, like the smaller model, is ruggedly built to stand up for years under heavy industrial use.

ELIMINATES HAZARDS TO SAFETY — prevents tangles of hose on the floor, cause of many industrial accidents. Permits welder to reel out only as much hose as he needs.

MAKES HOSE LAST LONGER — Reduces chances of hose being run over, cut in two or set on fire by a hot electrode. Users of the Weldreel report three to five times greater hose life.

EASY TO INSTALL ANYWHERE — Simple mounting permits installation in any position, on floors, walls, ceilings or on mobile equipment. Requires only 11" x 24" space.

CONVENIENT TO USE — Keeps hose in a handy location where it may be used alternately by two or more welders. Hose pays out freely and locks automatically at desired length. A slight tug releases lock, allowing the powerful spring to rewind hose onto reel.

See the Weldreel at your supply house or write us direct for descriptive literature.

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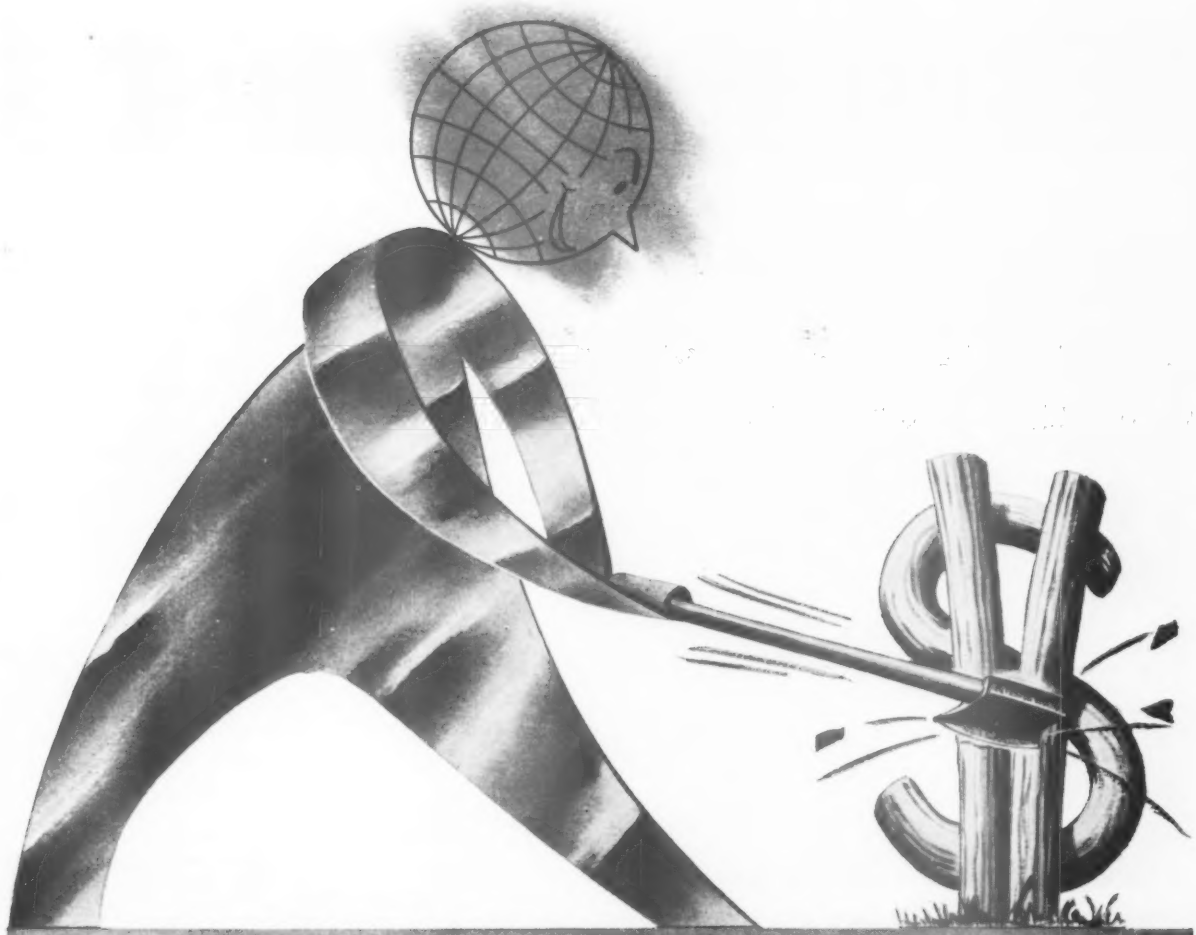
2,687,465—High-Frequency Induction Tube Welding—Thomas H. Crawford, Berkley, Mich.

This patent is on apparatus for performing the method of Patent No. 2,687,464 and includes means for advancing a longitudinally split tube blank along a predetermined path and means for moving the split edges into abutting engagement at a predetermined point. High-frequency induction means encircle the fixed path of the blank in advance of the point, while nonencircling inducing means are disposed to embrace the major peripheral portion of the tube between the encircling means and said point. These means extend along the blank edges for concentrating current to an increasing degree toward the said point.

2,687,466—Method of Welding of Composite Metal—Chester Mott, deceased, late of Evanston, Ill., by George A. Mott, executor, Evanston, Ill., assignor to Fansteel Metallurgical Corp., a corporation of New York.

This method relates to butt welding two composite metal sheets wherein each composite metal sheet consists of two layers of different metals permanently bonded with the two different metals having melting points which differ so much that the refractory metal cannot be maintained in a weldable condition when subjected to the normal welding temperature for the more refractory metal. The process includes the steps of welding the more refractory metal by disposing an arc-welding electrode adjacent the work to define a limited weld region and discharging a measured quantity of electric energy between the electrode and the work to create a momentary arc at the weld region, which energy is proportioned so that the momentary arc butt welds the more refractory metal together over the weld region for a limited depth. The metal sheets are displaced with reference to the electrode so that a succeeding but overlapping new welding region is selected and the new weld region is similar to the adjacent region after which the weld steps are repeated. Thus a number of adjacent overlapping weld regions are integrated to form a substantially continuous weld of the more refractory metal without substantial damaging effects upon the less refractory metal and thereafter welding the less refractory metal in a conventional manner.



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NATIONAL METAL EXPOSITION

NATIONAL METAL CONGRESS

LIST OF NEW MEMBERS

Effective July 31, 1954

MEMBERSHIP CLASSIFICATION

A—Sustaining Member
B—Member
C—Associate Member
D—Student Member
E—Honorary Member
F—Life Member

ALBUQUERQUE
O'Brien, William H. (B)

BOSTON
Olifierko, George (C)

CHICAGO
Harroun, Charles W. (C)
McEvilly, Jerry D. (C)
Schwartzbart, Harry (B)
Silliman, Stanley F. (C)
Taradejna, Stanley W. (C)

COLUMBUS
Boatfield, Richard (B)
Konn, Marvin L. (C)

DALLAS
Olson, Charles (B)

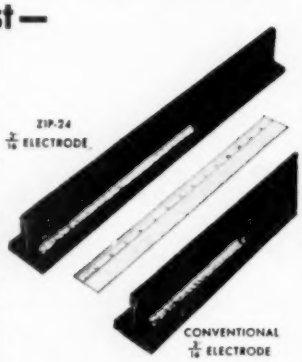
DAYTON
Martin, Orville Ellis (B)

HOUSTON
Hill, Edward V. (C)
Phillips, Preston D., Jr. (B)
Smith, Monroe E. (B)

INDIANA
Taylor, Edmund P. (B)

IOWA
Patterson, L. R. (B)

New Westinghouse ZIP-24 Electrode welds twice as fast— better, easier, too



FASTER WELDS—*50 to 70%* greater deposit rate. And an increase of *30 to 50%* in footage of fillet or lap weld per minute.
BETTER WELDS—balanced fillets give appearance of "machined finish" . . . no undercut with fillet and lap welds . . . perfect wall wash-up . . . easier slag removal . . . minimum spatter loss that reduces cleaning time.
EASIER WELDS—even-edged, smooth, finely rippled weld beads even when handled by an inexperienced operator. Ideal for "drag" technique.
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Name
Company
Address
City State
WJ-10-54

KANSAS CITY
Jacobi, E. F. (B)
Launder, John E., Jr. (B)

LONG BEACH
Cordray, Richard Irving (B)

LOS ANGELES
Alesch, Charles W. (B)
Merrell, Monroe F. (B)

MAHONING VALLEY
Stahl, Steve (B)

MARYLAND
Rummel, Edward F. (B)

NEW JERSEY
Merclean, Allen B. (C)
Worthy, John C. (B)

NEW ORLEANS
Goodgion, Carl W. (B)
Stoltz, Albert B., Jr. (B)

NEW YORK
Nuccel, Albert W. (C)
Ruddy, James P. (B)

NORTH CENTRAL OHIO
Eusey, Glen (C)
Frye, William L. (C)
Nungesser, Harry (C)
Stall, Roma (C)
Toms, Glen O. (C)

OKLAHOMA CITY
Christenberry, Harold R. (D)

OLEAN-BRADFORD
Field, William H. (C)

PHILADELPHIA
Kuhn, Wm. L., Jr. (B)

PORTLAND
Klaus, Conrad H. (B)

TOLEDO
Randels, George D. (B)

TRI CITIES
Smith, Edwin L. (C)

TUCSON
Stephens, George D., Jr. (B)

WESTERN MICHIGAN
Bambrick, Fred J. (B)

WICHITA
Johnson, Owen K. (C)

NOT IN SECTIONS
Ando, Kohei (B)
Heiremans, Eugenio D. (B)
Serebrennik, Jacobs (B)

Members Reclassified

During the Month of August

BOSTON
Toof, Hermon L. (C to B)

CINCINNATI
Jones, Embury T. (C to B)

CLEVELAND
Alexander, Edward E. (C to B)
Rudy, John F. (D to C)
Tupper Arthur S., Jr (C to B)

DETROIT
Lackner, Robert (C to B)

HARTFORD
Delisle, Leo A. (C to B)
Whitney, Burton O. (C to B)
Whitney, Thomas A. (C to B)

HOUSTON
Ewing, Josh F., Jr. (C to B)
Pratt, J. R. (C to B)
Sprague, Roy D. (C to B)

KANSAS CITY
Payne, Joseph M. (B to A)

LOS ANGELES
Reed, Virgil C. (C to B)

MILWAUKEE
Baumler, Harold (C to B)

NEW JERSEY
Joyce, Arthur T. (C to B)
Waugh, H. C. (C to B)

NEW YORK
Fenton, Edward A. (C to B)
Humberstone, J. H. (B to A)

PHILADELPHIA
Brumder, H. E. (B to A)
List, Walter G. (C to B)

SYRACUSE
Wolfe, Harry C. (C to B)

SECTION NEWS AND EVENTS

as relayed to C. M. O'Leary

Annual Report

Kansas City, Mo.—During the 1953–54 season, the *Kansas City* Section held nine regular meetings; one picnic, one plant tour, one Ladies' Night, one panel discussion program and five technical meetings. The picnic was held during September at Swope Park. The plant tour was held at the Buick-Oldsmobile-Pontiac assembly plant in North Kansas City, Mo. Members and their guests got a very good look at the methods and tools used in high production resistance welding. A very good talk, interesting to the mixed group, was given by a representative of the FBI at the Ladies' Night held in December.

The Section continued to precede each dinner meeting by a Social Hour, which has proved valuable in getting the members acquainted and starting the dinner on time.

This year the Kansas City Section undertook a sponsor-membership program. This program was very well received by those companies contacted. In a very short period the Section was able to obtain 20 sponsor members.

Officers

Kansas City, Mo.—The following is a list of the Officers and Committee Chairmen appointed by the members of the *Kansas City* Section for 1954–55.

Chairman—P. D. Blake, Hohenschild Welders Supply Co.
1st Vice-Chairman—Dean E. Broderson
Secretary—Blaine G. Harrington, Jr., Air Reduction Sales Co.
Treasurer—Frank G. Singleton
Chairman, Membership Committee—Andy Anderson
Chairman, Program Committee—Thomas H. Nicholl, Lincoln Electric Co.
Technical Representative—Leslie N. Williams, Darby Corp.

Art of Welding Contest

Long Beach, Calif.—The photo reproduced herewith shows part of the Executive Committee of the *Long Beach* Section and the trophies which were awarded for the Excellence in the Art of Welding Contest. Members in the photo are (*left to right*): Glenn Schuyler, Shell Walling, Carlos Redding, Gail Beckstrand, J. J. Carl, Charles Breese, O. B. Bowers, Frank Pope, Lee Schexschnider, Tommy Lewis and Mal Teeter. The photo was taken by another member, Harry Butler.

Long Beach

Long Beach Meetings

Long Beach, Calif.—The *Long Beach* Section advises that it will hold its monthly technical meetings at a new location starting in September at the Victor Hugo Restaurant, Colonial Room, 730 W. Broadway, Long Beach, Calif. The third Friday of the month will remain as the regular meeting date; 6:30 P.M. is the time to start assembling.

Committee Appointments

Newark, N. J.—In addition to the Officers listed in the August "Section News and Events" the *New Jersey* Section announces the appointment of the following committee chairmen:

Chairman, Membership Committee—T. McElrath, Linde Air Products Co., Newark, N. J.
Chairman, Program Committee—H. Hughey, Airco Equipment Mfg. Div.
Technical Representative—W. Benz, M. W. Kellogg Co., Jersey City, N. J.

New Orleans Officers

New Orleans, La.—The *New Orleans* Section announces the election of the following Officers:

Chairman—W. G. Blackwell, Consolidated Welding Supplies, Inc.
1st Vice-Chairman—A. A. Boudousquie, Southern Industrial Sales, Inc.
Secretary—W. A. Massimini, Gulf Engineering Co., Inc.
Treasurer—R. P. Wilson, Linde Air Products Co.

Committee Members

Pittsburgh, Pa.—The following members have been appointed to the respective Committees of the *Pittsburgh* Section for the 1954–55 season.

Educational Committee:
Julius Heuschkel, Westinghouse Electric Corp., *Chairman*
R. B. Lincoln, Pittsburgh Testing Laboratory
Robert M. Stuchell, Pittsburgh-Des Moines Steel Co.

Reception Committee:
H. Edward Cable, D & R Electric Co., *Chairman*
Francis C. McDevitt, McDevitt Welding Service
E. J. Minnick, National Cylinder Gas Co.

Technical Representative—Donald H. Marlin, Dravo Corp.

Program Committee:
H. L. Anthony, Mellon Institute of Industrial Research, *Chairman*
J. K. Kerr, Williams & Co.
W. B. Brubaker, Air Reduction Sales Co.

Membership Committee:
Robert T. Brown, Metal & Thermit Corp., *Chairman*
J. J. Sullivan, Arcway Equipment Co.
L. Scott McKeever, Pittsburgh Testing Laboratory

Newly Elected Officers

Schenectady, N. Y.—The *Northern New York* Section announces the election of the following officers and committee chairmen for 1954–55.

RACO gives you UNINTERRUPTED

COSTS NO MORE ... SOMETIMES LESS

MILD STEEL • MEDIUM CARBON • LOW ALLOY
ALUMINUM • BRONZE • SPECIAL PURPOSE ALLOYS
CHROME-MOLY • STAINLESS • NICKEL • TITANIUM

THREADWOUND COILS
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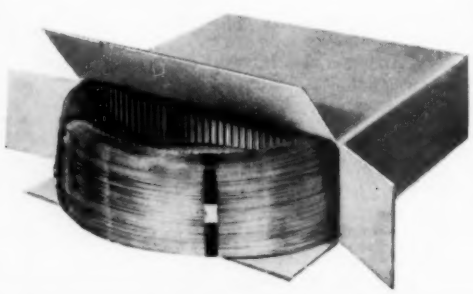

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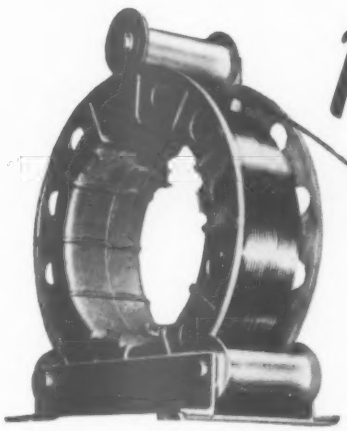

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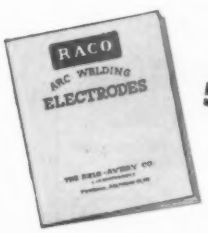

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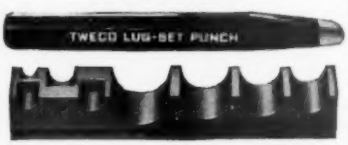

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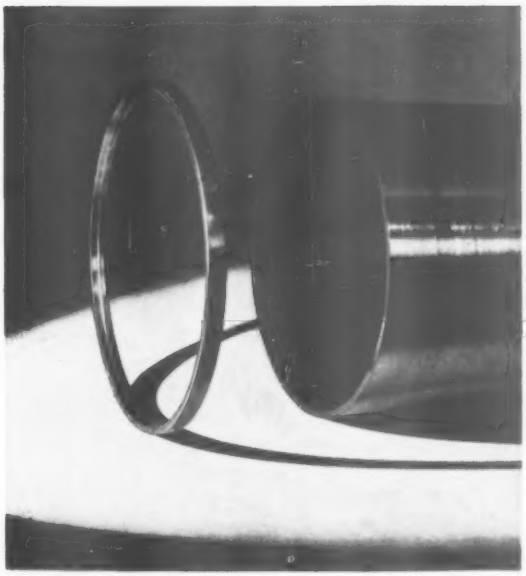

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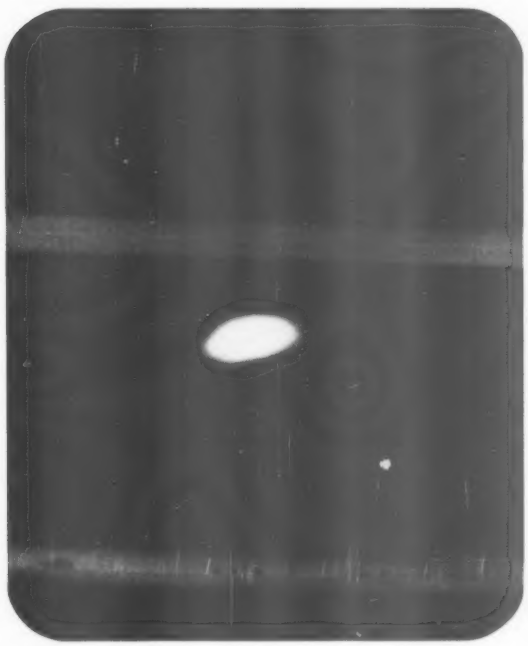

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Supplement to the Welding Journal, October 1954

Crack-Starter Tests of Ship Fracture and Project Steels

In rimmed and semikilled steels, steels have no appreciable ductility in the presence of a crack at temperatures which give Charpy V values below 10 ft-lb. Fully killed steels are related to higher energy values

by P. P. Puzak, M. E. Schuster and W. S. Pellini

Abstract

The performance of rimmed and semikilled steels involved in ship fractures is investigated by means of crack-starter tests. In these tests a sharp crack is introduced in the steel and the relative resistance to the initiation and propagation of fracture is established over the range of service temperatures. It is demonstrated that in the presence of the sharp crack the steels have no appreciable ductility when the temperature falls below the Charpy V 10 ft-lb transition; accordingly, fracture initiation is readily developed. The propagation of brittle fractures becomes difficult at temperatures above the Charpy V 15–25 ft-lb transitions. These findings are in agreement with National Bureau of Standards data for ship fracture plates. It is demonstrated that fully killed steels do not follow these rules and that the respective initiation and propagation characteristics of fracture are related to higher Charpy V values. Wide plate, tear and Charpy V test data are discussed with reference to differences related to deoxidation practice.

P. P. Puzak, M. E. Schuster and **W. S. Pellini** are with the Metallurgy Division, Naval Research Laboratory, Washington, D. C.

Scheduled for presentation at the AWS National Fall Meeting to be held in Chicago, Ill., Nov. 1–5, 1954.

The research described in this report was sponsored by the Ship Structure Committee as part of its research program. The work was conducted under the general supervision of the Explosion Test Advisory Committee of the Ship Structure Committee. The opinions expressed herein are those of the authors and do not necessarily represent those of the Ship Structure Committee, the Explosion Test Advisory Committee, or of the Department of the Navy.

INTRODUCTION

IT IS generally recognized that notches or cracks are required to develop brittle fracture at ambient temperatures in structural steels which are classed as highly ductile by conventional tensile tests. In the absence of notches these steels demonstrate high ductility to very low temperature, i.e., behave as predicted by the tensile tests. For example, structural steel prime plate may be deformed extensively by explosion loading to temperatures as low as −60 to −80° F.[1, 2] In the presence of sharp crack-like defects it is possible to fracture such steels at 20 to 40° F without visible deformation by the impact of a dropping weight. Figure 1 illustrates the extensive explosion bulge deformation which may be developed without fracture at −40° F in a prime plate of ABS −A steel and the brittle fracture of a similar steel at 20° F resulting from the presence of arc strikes associated with small cracks.

In order to develop brittle fracture with small or essentially nil deformation two requirements must be met—not only must a sharp notch be present but the steel must be at a proper temperature. Depending on the sharpness of the notch, a temperature transition is obtained such that the steel changes from being insensitive to the presence of the notch to being highly sensitive. It is this change, particularly for the case of sharp, crack-like notches, with which the designer of welded ships and other large structures is concerned.

Fig. 1 Relative performance of ABS-A type ship plate in prime condition (bottom) and in presence of sharp crack defects (center)

The prime plate represents material taken from stock and the arc-strike plate represents a sample of material taken from a T-2 tanker which fractured at 35° F.

In the simplest possible terms: the designer wishes to know the temperature at which high sensitivity to sharp notches is developed for a specific steel. Furthermore, this temperature must be predictable from the results of relatively simple laboratory tests.

In order to obtain this information the Naval Research Laboratory has conducted extensive tests of ship steels using the sharpest possible type of notch—a cleavage crack. The methods have been described in detail in previous reports.[3, 4] Briefly, a bead-on-plate of a highly brittle, hard-surfacing weld is deposited on the test plate; as the weld cracks on loading an ultra-sharp notch is introduced in the steel. Two types of "crack-starter" tests were evolved:

1. *Drop Weight Test.* Used to establish the temperature at which the steel loses its ability to develop more than a minute amount of deformation in the presence of the crack-like notch. In this test a $3^1/_2$ in. × 14 in. × plate thickness specimen is loaded by the impact of a dropping weight. A stop is used to limit the deformation to 2 deg of bend angle following the development of the weld crack. Details pertaining to

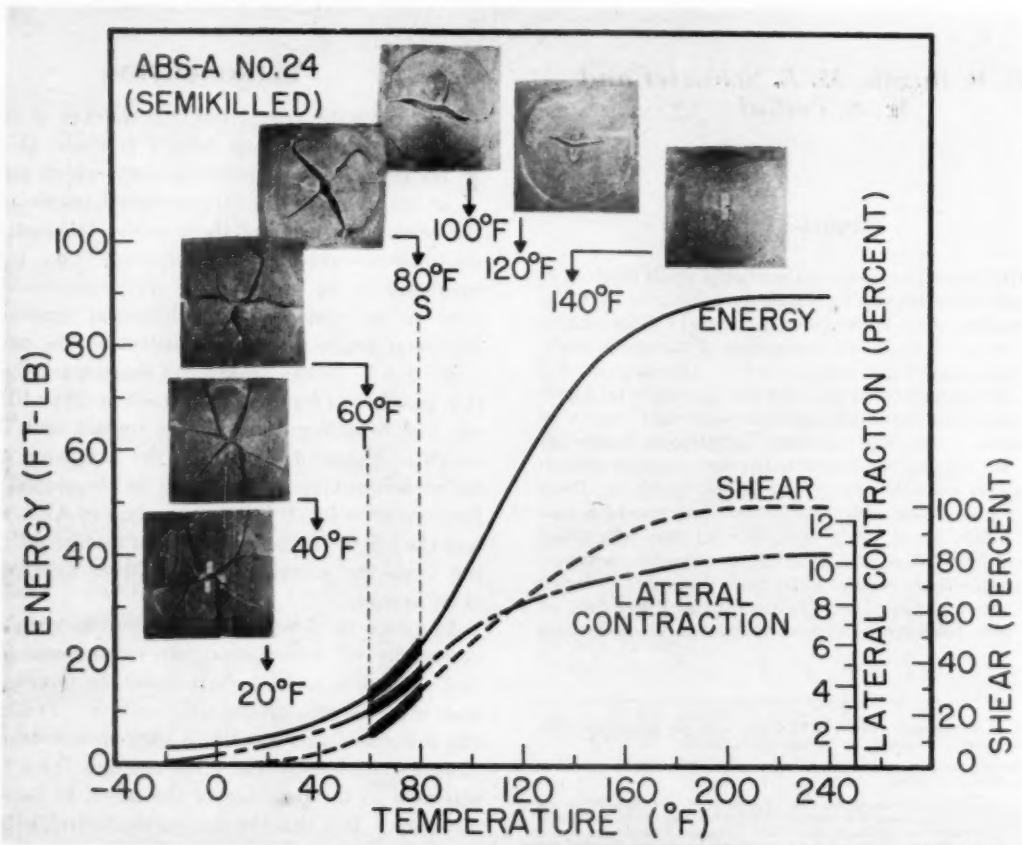

Fig. 2 Relationship of explosion crack-starter tests to Charpy V transition curves for typical ABS-A type steel (0.23% C, 0.45% Mn, 0.05% Si; 1-in. thick)

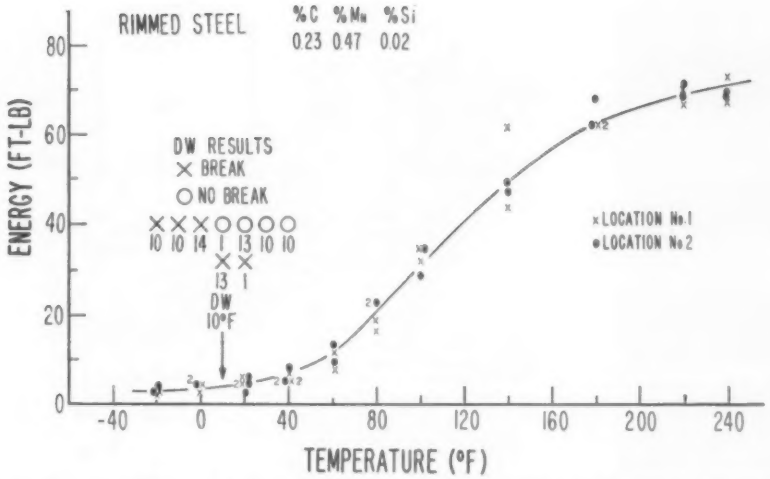

Fig. 3 Correlation of drop weight nil-ductility transition to Charpy V energy curve

[r] Drop weight specimens cut randomly from 5/8- x 60- x 120-in. plate; location *1* and *2* Charpy specimens taken from diagonal corners of plate.

testing equipment and procedures are furnished in the appendix.

2. *Explosion Test.* Used to establish the temperature range of transition from easy to difficult propagation of fractures. In this test a 14 in. × 14 in. × plate thickness specimen is placed over a circular die and explosion loaded.

Figure 2 illustrates the typical relationship of explosion crack-starter tests of semikilled and rimmed ABS-A type ship plate steels to the Charpy V transition curves relating to energy, fracture appearance and notch deformation. The change from shatter type fractures to fracture refusal corresponds essentially to the range of the Charpy V transitions. The change from complete fracture "*T*" (through) to partial fracture "*S*" (stop) is of particular significance in denoting a transition in the properties of the steel with respect to fracture propagation through the lightly loaded edge regions of the test plate. In the *T* to *S* range, the thickness of the shear lips developed at the surface of the fracture becomes equal to the 0.020–0.30 in. thickness found to be the maximum observed for the ship fracture plates.[3, 4]

Figure 3 illustrates the typical relationship of the drop weight test nil-ductility transition (highest temperature at which the steel is unable to withstand 2 deg of bend in the presence of the sharp crack) to the Charpy V energy curve. Ordinarily, six to eight specimens are utilized to establish the nil-ductility transition with duplicate or triplicate tests at each critical temperature (10° F above and at the transition temperature). In this case the transition temperature was determined to be 10° F using six specimens and then a large number of additional tests were performed to illustrate the degree of reproducibility. Of the 14 tests at 10° F only one specimen failed to fracture and of 14 tests at 20° F only one specimen developed fracture. At 30° and 40° F all specimens resisted fracture and at 0, −10 and −20° F all specimens fractured. The test specimens are shown in Fig. 4. This high degree of reproducibility which may be suprising for fracture tests results from two factors:

1. The reproducibility of the notch condition—the brittle weld always develops the same sharp cleavage crack.

2. The very large change with increasing temperature in the level of deformation required to develop fracture. While 2 deg of bend could not be developed at 10° F it is demonstrated, Fig. 5, that at 30° F and higher temperatures drastic bending is permitted without fracture.

It is of interest that at temperatures of drop weight fracture the explosion test plates break "flat," i.e., without visible deformation. At higher temperatures bulging is developed indicating that the fracture was difficult to start and required "forcing."

If sharp, crack faults were actually responsible for the initiation of ship fractures it should be expected that the crack-starter tests should show the same correlation to the Charpy V energy curve as demonstrated by the NBS investigation of fractured ship plates.[5, 6] The loading conditions in the ships are such that fracture must initiate at essentially nil deformation levels (very small amounts of deformation at positions of unfavorable design). This may be recognized as the test con-

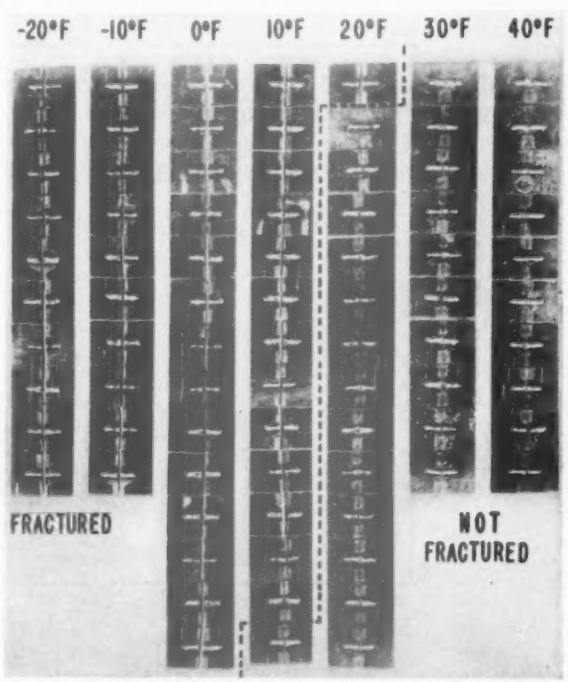

Fig. 4 Drop weight test specimens used to establish data presented in Fig. 3

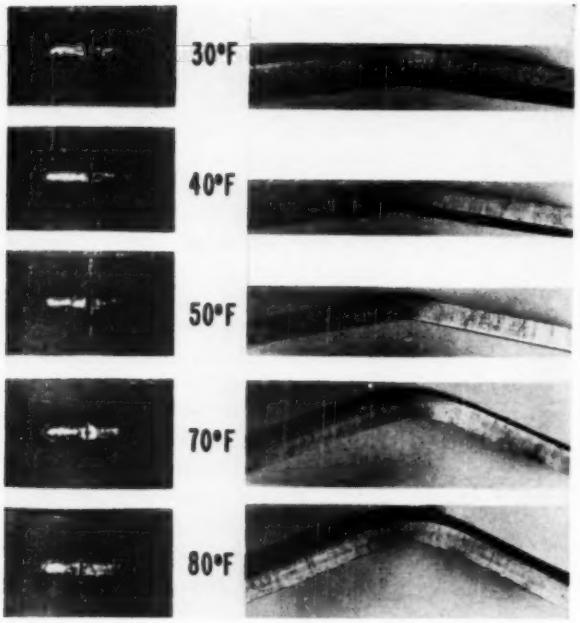

Fig. 5 Illustration of drastic bending without fracture possible at 30° F and higher temperatures for steel shown in Figs. 3 and 4

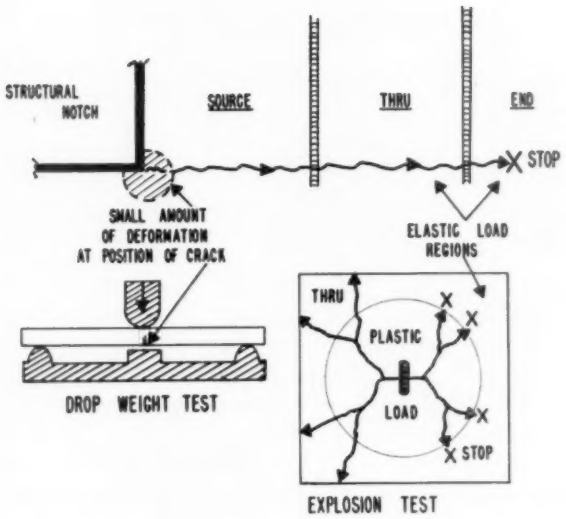

Fig. 6 Correspondence of drop weight test to conditions of fracture initiation in service and relationship of "thru" and "stop" (T-S) behavior in explosion test to propagation or stoppage of fractures in service

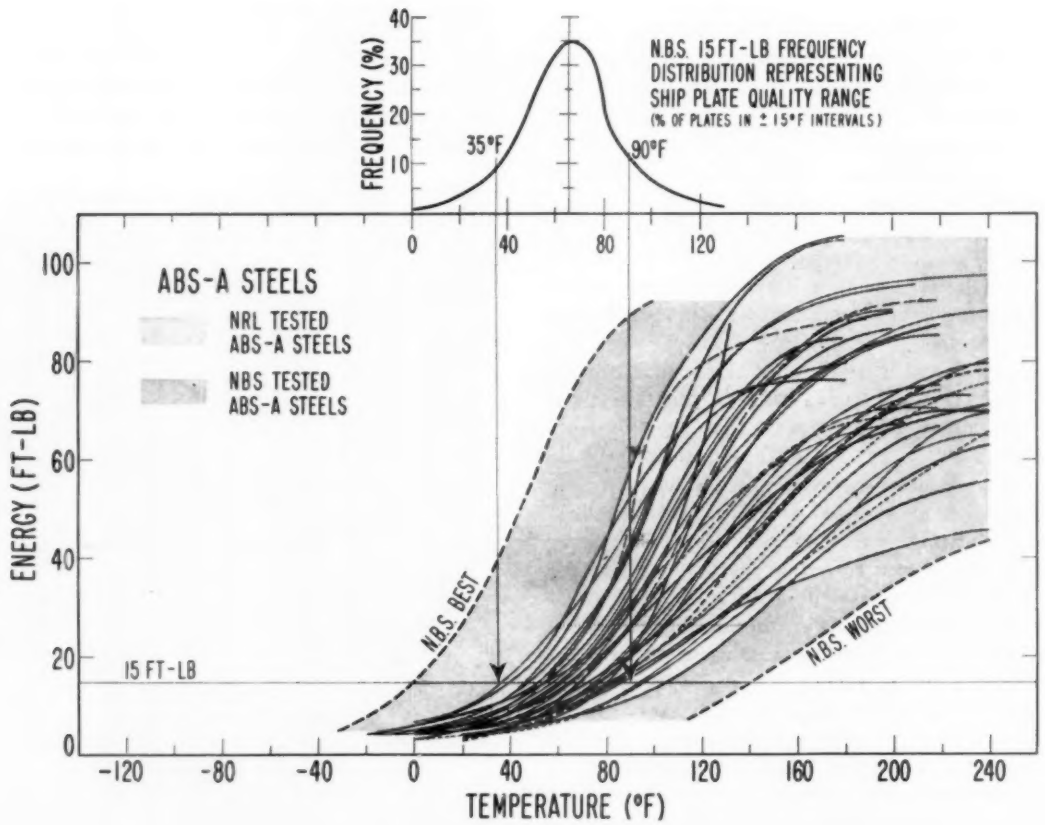

Fig. 7 Charpy V energy transition curves of all ABS-A type steels subjected to crack-starter tests in comparison to National Bureau of Standards charpy data for ship fracture steels

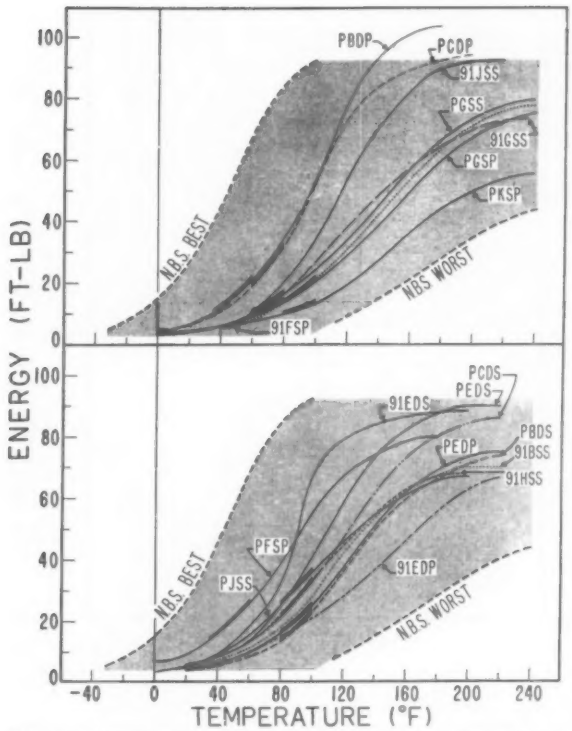

Fig. 8 Charpy V energy transition curves of rimmed (top) and semikilled (bottom) ship fracture steels subjected to crack-starter tests

dition which is imposed by the drop weight test (Fig. 6, *left*). Once started, the fractures of ship structures must necessarily propagate through regions of elastic loading. The edge regions of the explosion test plates are supported by the die and therefore do not develop bulge (plastic) deformation such as the central regions. Thus, the edge regions provide a critical evaluation for the fracture resistance of elastic load regions (Fig. 6, *right*).

The above stated considerations represent the theory of the test procedures; the proof of the applicability of the theory must be found in the test results. The initial test results of ABS-A type steels indicated that the drop weight test correlated with fracture initiation conditions of ship fracture "source" plates and that the *T–S* fracture transition of the explosion test correlated with the limiting conditions of fracture propagation as judged by ship fracture "through" and "end" plates. In order to obtain a more rigorous check of the correlation features, the Ship Structure Committee requested crack-starter tests of actual ship fracture steels. During the progress of the investigation it was deemed of interest to compare the results of various conventional full plate thickness notch tests (wide plate and tear tests) with crack-starter tests. For this purpose "project steels" used in previous investigations were made available for crack-starter tests.

TEST RESULTS

The Charpy V transition curves of all of the ABS-A type steels which have been subjected to crack-starter tests are presented in Fig. 7. The range of these curves is illustrated to fall in the center of the range which covers all ship fracture steels investigated by the NBS. Figure 8 presents the Charpy V energy transition curves obtained for 18 ship fracture plates (11 NBS ship No. 52, 7 NBS ship No. 91). Rimmed steel curves are grouped at the top and semikilled steel curves at the bottom of the figure. In comparison to the range of Charpy V energy transitions for all of the ship fracture steels tested by the NBS, these steels are observed to represent average material, i.e., on the basis of Charpy V energy 15 ft-lb distribution (see Fig. 7) these steels fall within the limits encompassing approximately 80% of all ship fracture steels tested by National Bureau of Standards.

The heavy band portions superimposed on the curves of Fig. 8 represent the temperature positions of the explosion crack-starter test *T–S* points. The lower end of the band represents the highest temperature at which the brittle cracks propagated *Through* (*T*) the lightly loaded hold-down regions of the test plate, and

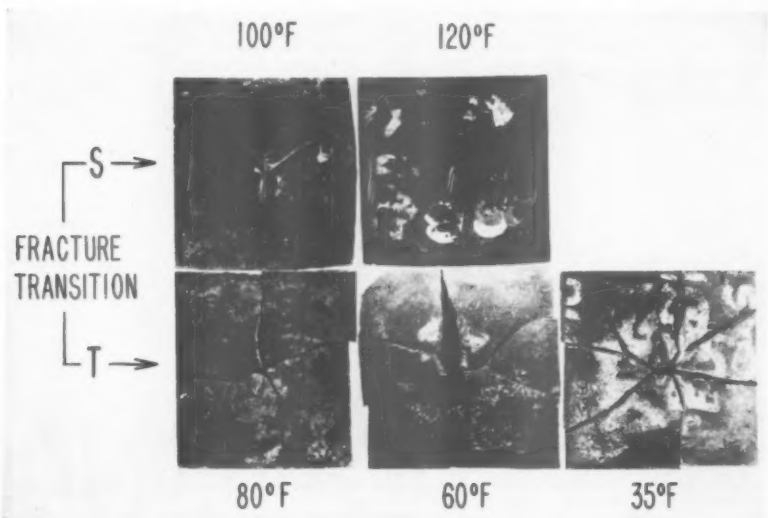

Fig. 9 Crack-starter, explosion test series of ship fracture steel PEDP depicting T-S fracture transition

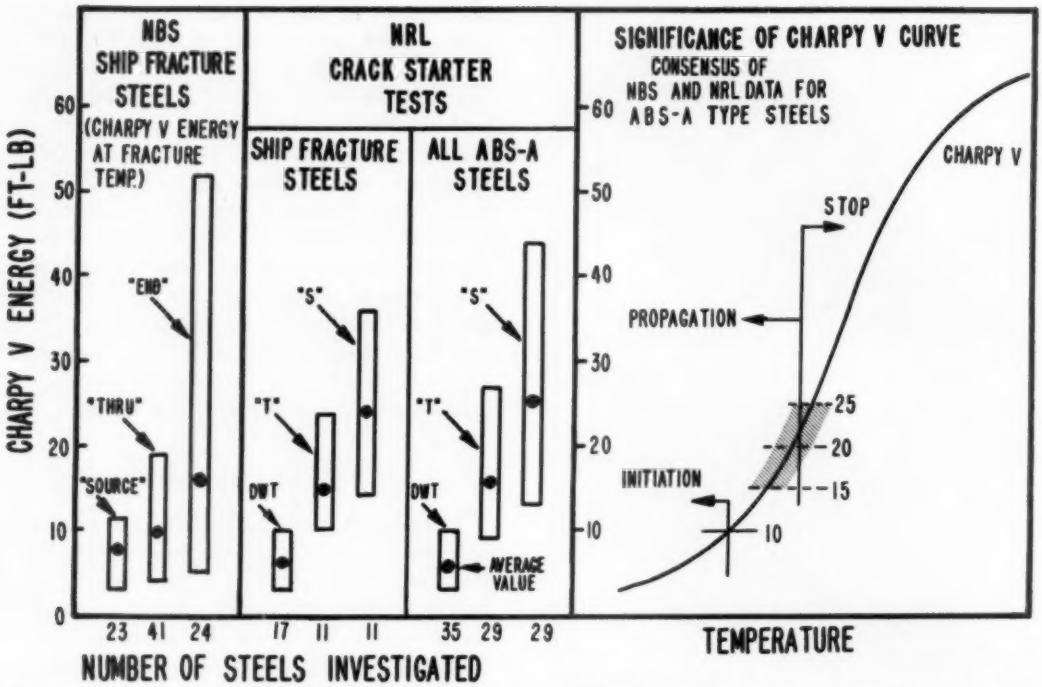

Fig. 10 Summary graph depicting correspondence of NBS ship fracture data and NRL crack-starter test data to Charpy V energy

the upper end of the band represents the test temperature (20° F higher) at which the brittle cracks are confined (*Stop—S*) to the plastically deformed, central regions of the bulge. Figure 9 illustrates the fracture characteristics at various temperatures for one of the ship fracture steels. Table 1 lists the chemistry and provides a summary of the crack-starter test data for the various ship fracture steels.

Figure 10 summarized the correspondence of the NBS ship fracture data and the NRL crack-starter test data. The NBS investigation demonstrated that "source" plates were characterized by Charpy V energy values of 11.4 ft-lb maximum (avg 7.4 ft-lb) at the fracture initiation temperature. As denoted by the schematic illustration at the left of the figure, the NBS ship fracture data and the drop weight test data are in agreement that the Charpy V 10 ft-lb transition temperature marks the critical temperature for fracture initiation of ABS-A steels. The drop weight test data indicate that without exception the 35 ABS-A steels tested, including 17 ship fracture plates, required temperatures of less than that of the Charpy V 10 ft-lb transition for fracture initiation in the absence of appreciable deformation. The average Charpy V energy at the drop weight transition temperature of 6.1 ft-lb for the 17 ship fracture steels and 5.9 ft-lb for all ABS-A steels are for all practical purposes exactly equivalent to the NBS 7.4 ft-lb average value.

When considering the NBS data for "thru" plates it must be recognized many plates in the path of frac-

Table 1—Crack-Starter Test Results of Ship Fracture Steels

Plate	Drop weight		Explosion fracture transition								
			Thru (T)		Stop (S)		%				
No.	°F	Ft-lb	°F	Ft-lb	°F	Ft-lb	C	Mn	Si	P	S
PBDP	10	5	35	10	60	21	0.12	0.36	0.01	0.006	0.030
PCDP	0	5	60	19	80	32	0.11	0.33	0.01	0.019	0.035
PKSP	50	7	80	10	100	14	0.19	0.31	0.01	0.020	0.028
PGSS	10	4	60	10	80	16	0.21	0.36	0.01	0.030	0.028
PGSP	0	4	60	14	80	20	0.20	0.37	0.01	0.020	0.025
91FSP	0	3	80	14	100	21	0.22	0.37	0.01	0.008	0.030
91JSS	20	4	..	..	...	..	0.21	0.37	0.01	0.005	0.024
91GSS	20	5	..	..	...	..	0.27	0.37	0.01	0.010	0.035
PEDS	50	10	..	..	...	..	0.25	0.45	0.04	0.010	0.028
PEDP	40	6	80	16	100	25	0.23	0.41	0.04	0.006	0.028
PJSS	..	..	80	24	100	36	0.26	0.39	0.10	0.020	0.028
PBDS	35	5	80	13	100	22	0.24	0.39	0.03	0.030	0.028
PFSP	20	9	35	13	60	26	0.25	0.36	0.04	0.020	0.028
PCDS	35	7	80	21	100	32	0.21	0.42	0.02	0.020	0.025
91BSS	30	6	..	..	...	..	0.29	0.42	0.07	0.010	0.039
91EDS	40	9	..	..	...	..	0.19	0.48	0.09	0.009	0.030
91HSS	10	5	..	..	...	..	0.31	0.49	0.10	0.012	0.037
91EDP	60	10	..	..	...	..	0.27	0.52	0.08	0.010	0.031

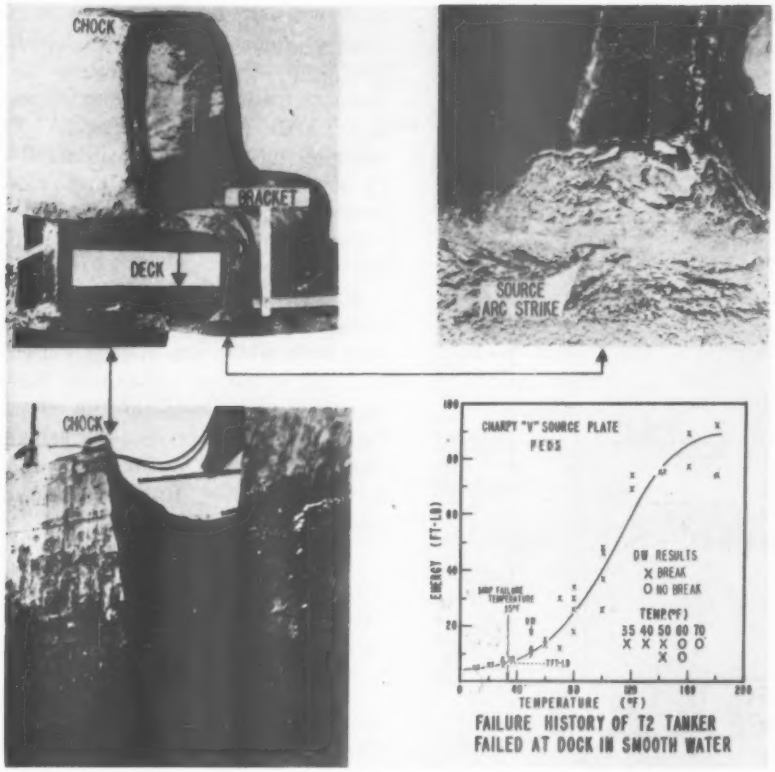

Fig. 11 Catastrophic ship failure initiated by arc-strike defect at 35° F. Correlation of source plate Charpy V and drop weight test data with service performance

ture were potentially of "source" type. The most significant aspect of the "thru" plate data is the fact that no plates of more than 19 ft-lb Charpy V energy at fracture temperature fall into this class. This signifies that values in excess of 19 ft-lb always precluded the propagation of fractures. In all cases plates which showed more than 19 ft-lb fell into the "end" type as shown by the "end" group. The fact that plates of less than 19 ft-lb were also contained in the "end" grouping may be explained by stress factors, inasmuch as fracture propagation may be prevented by low stress level (or compression regions) as well as by material properties.

The explosion crack-starter tests do not have the variable of low or compression stresses to cause fracture stoppage at temperatures of low Charpy V energy values. If fracture stoppage is obtained at the edge regions it must be due solely to material properties which preclude propagation. The overlap in the Charpy V energy values for T and S type behavior

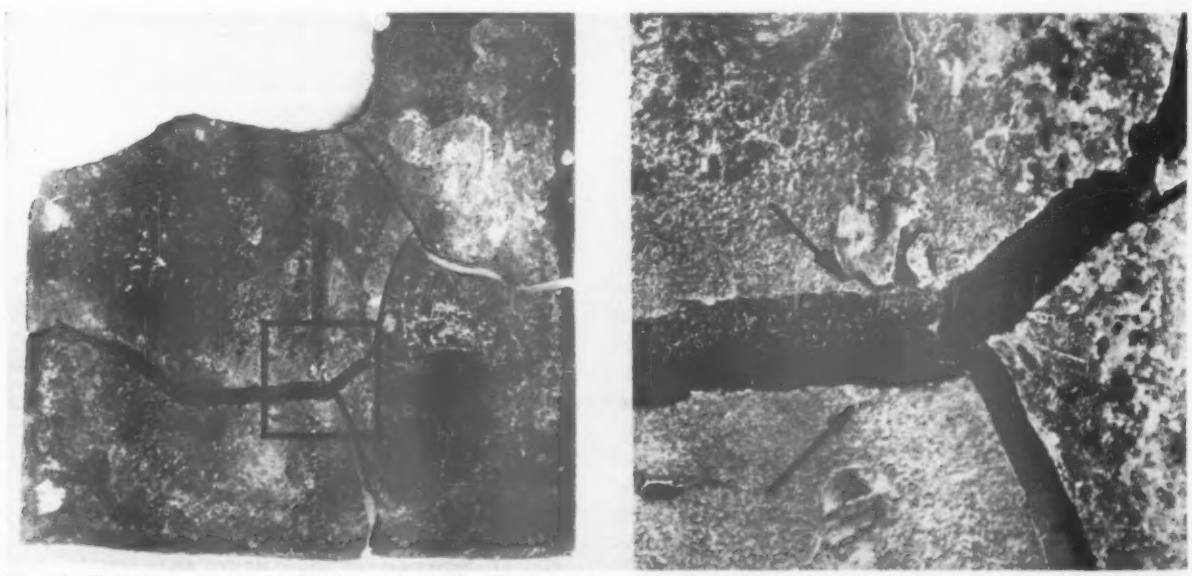

Fig. 12 Crack-starter test of ship fracture steel. Crack-starter weld ignored and fracture initiated by natural crack defect in fillet weld. Test 60° F, plate PBDS

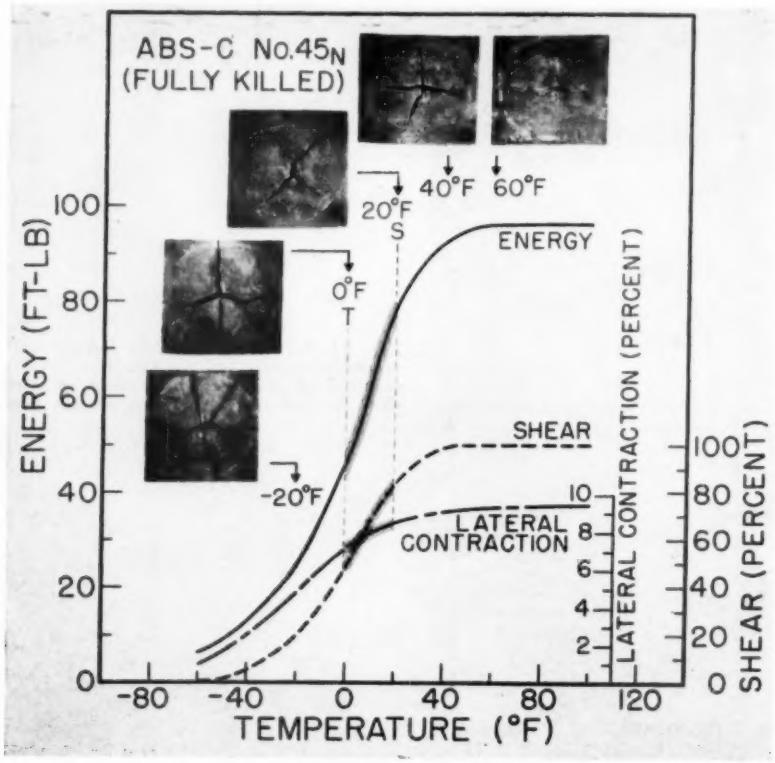

Fig. 13 Relationship of explosion crack-starter tests to Charpy V transition curves for typical normalized ABS-C (fully killed) type steel

Note higher position on Charpy V curves of *T-S* range as compared to ship plate steel in Fig. 2 (0.17% C, 0.77% Mn, 0.23% Si, 0.02% Al; 1 in. thick).

which indicates the change from easy to difficult fracture propagation is in the range of 13 to 27 ft-lb when considering extremes. If averages are considered the overlap is 15 to 25 ft-lb. This signifies that in most cases 15 ft-lb was the highest value which permitted propagation and 25 ft-lb the lowest value which prevented propagation. In all cases values in excess of 27 ft-lb prevented propagation and values of less than 13 ft-lb permitted propagation. The explosion tests thus define the 15 to 25 ft-lb transition range as the critical temperature range of change with respect to fracture propagation when considering material properties only. This is in excellent agreement with the NBS finding that 19 ft-lb was the highest value for a "thru" plate.

On the basis of these data it may be concluded that the crack-starter tests show excellent correlation with service and agree with the NBS findings that the significance of the Charpy V transition curve to service is as illustrated in Fig. 10 (*right*).

The test results of two of the NBS ship No. 52 (a T-2 type tanker which broke in half at a temperature of 35° F while tied at a dock in relatively smooth water) ship fracture steels are of sufficient interest to be discussed in detail. Figure 11 depicts the ship failure which initiated in an arc strike of one of the starboard deck plates (PEDS). At the ship failure temperature the source plate developed 7 ft-lb Charpy V energy. The nil-ductility (drop weight test) transition for this plate was 50° F at which 10 ft-lb Charpy V energy was developed. The drop weight test results indicate at the ship failure temperature of 35° F the source plate was 15° F below the nil-ductility transition (50° F) of the plate, i.e., the steel was potentially susceptible to fracture initiation in the presence of sharp crack defects.

Another item of interest is the initiation of fracture from a narrow fillet weld which was evidently used for a clip or similar attachment during the construction of the ship. Figure 12 illustrates that the crack-starter weld was ignored and the fracture initiated from a natural crack defect in the fillet weld.

COMMENTS RELATING TO CRACK-STARTER TESTS OF STEELS OTHER THAN ABS-A

It should be recognized that the correlation of crack-starter tests to Charpy V energy curves for fully killed steels such as the ABS-C type and the Navy HTS type is not the same as found for the semikilled and

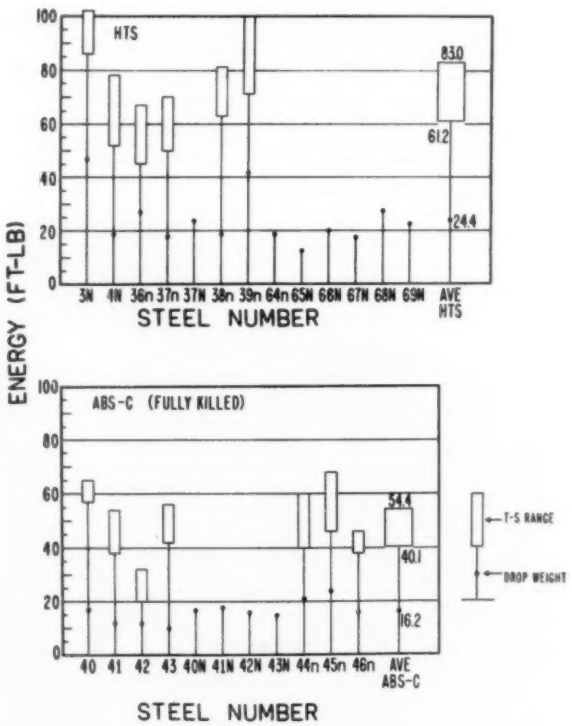

Fig. 14 Summary of crack-starter tests correlation to Charpy V energy for fully killed steels (N = mill normalized, n = laboratory normalized)

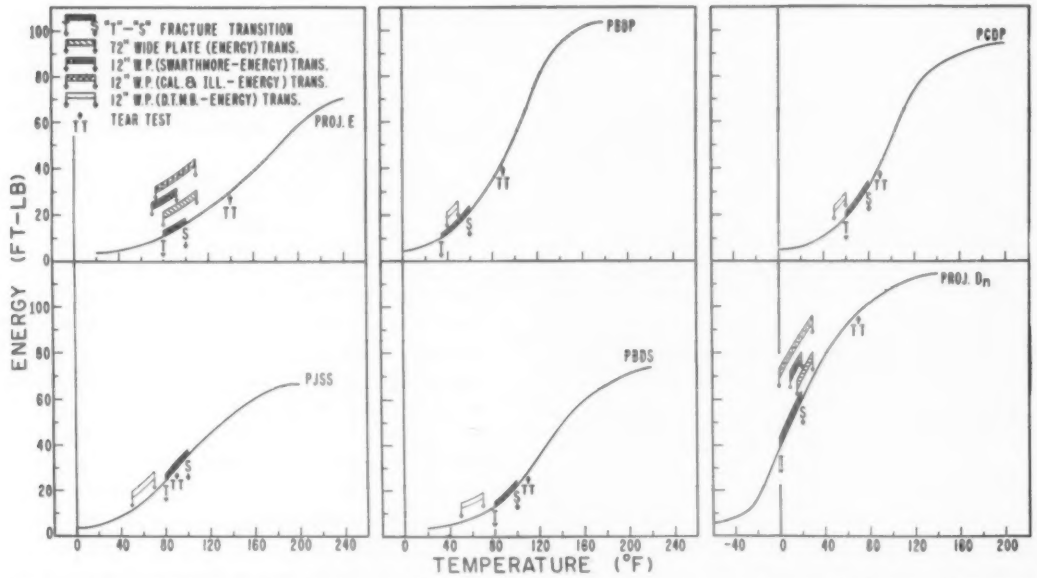

Fig. 15 Relationships of explosion, wide plate and tear test fracture transitions to Charpy V energy transitions

rimmed ABS-A type steels. Figure 13 illustrates that the *T–S* transition for these steels occurs at temperatures corresponding to higher positions on the Charpy V curves. The drop weight test also shows relationships to higher positions on the Charpy V energy curve. Figure 14 summarizes the results of *T–S* and drop weight nil-ductility determinations for ABS-C and HTS steels which have been tested to date.[7] It is noted that the average Charpy V energy at the drop weight transition for ABS-C steels is 16.2 ft-lb and for the HTS steels 24.4 ft-lb. The *T–S* range for these two steels averages 40 to 54 ft-lb and 61 to 83 ft-lb, respectively.

CORRELATION OF CRACK-STARTER TESTS WITH WIDE PLATE AND TEAR TESTS

Wide plate and tear tests may be considered plate fracture tests featuring machined or saw-cut notches. The results of these tests are evaluated on the basis of the range of temperature over which a "scatterband" of high and low values of cleavage fracture is developed. The fracture transitions reported[8–12] for the wide plate tests correspond to the full spread of the "scatterband" range while the transitions reported[13,14] for the tear tests represents the highest temperature at which one or more of four specimens broke with more than 50% cleavage fracture.

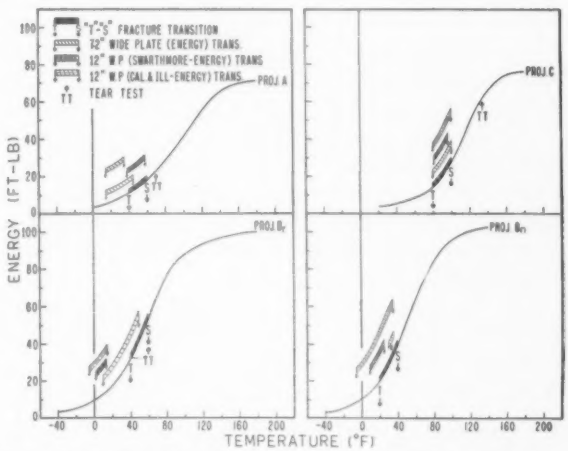

Fig. 16 Relationships of explosion, wide plate and tear test fracture transitions to Charpy V energy transitions

Six project steels and four ship fracture steels which had previously been subjected to wide plate and tear tests were available for explosion and drop weight crack-starter tests. Figures 15 and 16 depict the results of the wide plate, tear and explosion tests as related to the Charpy V energy transitions established for these steels at NRL. Drop weight test results and related Charpy V energy values are shown in Table 2.

Table 2—Crack-Starter Test Results of Project Steels

Project No.	Drop weight		Explosion fracture transition — Thru (T)		Explosion fracture transition — Stop (S)		%				
	°F	Ft-lb	°F	Ft-lb	°F	Ft-lb	C	Mn	Si	P	S
E	30	4	80	11	100	16	0.25	0.35	0.02	0.008	0.040
A	20	6	40	11	60	18	0.23	0.48	0.02	0.009	0.039
C	30	5	80	14	100	28	0.21	0.44	0.05	0.010	0.037
B_r	0	10	40	32	60	53	0.16	0.72	0.05	0.013	0.032
B_n	−10	9	20	21	40	40	0.16	0.73	0.04	0.011	0.033
D_n	−20	16	0	39	20	61	0.18	0.54	0.25	0.015	0.029

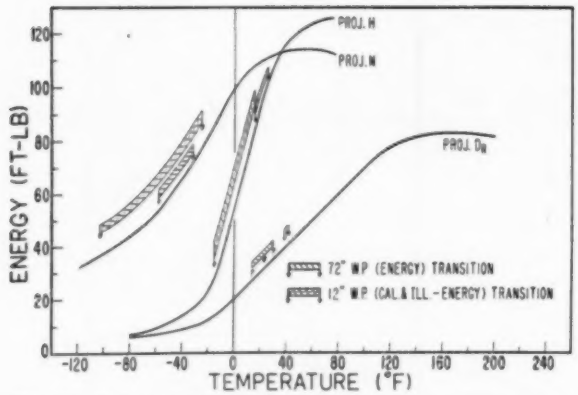

Fig. 17 Relationship of wide plate fracture transitions to Charpy V energy transitions for various fully killed steels

The following may be concluded:

1. Explosion test fracture transitions (*T–S*) generally occur at a temperature range which overlaps the range displayed in the wide plate tests.

2. When the wide plate transitions (or the *T–S* fracture transition) are related to the Charpy V energy curves, significantly higher energy values are obtained for the fully killed steel (D_n) as compared to the rimmed and semikilled ABS-A type steels (E, A, C, PBDP, PCDP, PJSS and PBDS). This pattern of behavior persists if wide plate data for additional fully killed steels are considered (Fig. 17). In other words, wide plate tests data corroborate crack-starter test results in indicating that fully killed steels are susceptible to fracture at temperatures of higher Charpy V energy than noted for ABS-A type steels.

3. The tear test transitions generally occur at higher positions than the fracture transitions displayed in wide plate and explosion bulge tests. For the various ABS-A steels the correlation with Charpy V energy varies from 22 to 60 ft-lb (22, 60, 55, 30, 40, 40, 35) with the range of 30 to 40 ft-lb being most common. In relation to the NBS, NRL and wide plate data the tear test appears to provide a conservative estimate of the danger temperature with respect to propagation.

COMMENTS RELATIVE TO PROJECT STEEL CHARPY V DATA

From previous investigations involving project steels, it has been reported and widely quoted that Charpy specimens are not amenable to correlation studies. This contention was based in great part on results for project Steels A and C for which widely different fracture transitions in wide plate tests but essentially identical Charpy V energy transitions have been reported in the literature.[15] In this respect it is of interest to review all available data which serve to indicate the uniformity of quality for the various plates of the project steel heats.

In Fig. 18, the original Charpy V data for six project steels[16] are compared to those obtained at this laboratory. Essentially equivalent curves are obtained for E, A, B_n and D_n. For Steel B_r the two sets of data indicate significant differences between plates within the same heat. The correlations shown in Fig. 16 are poor for B_r, which fact may be explained on the basis of plates of different quality.

The various Charpy V curves reported for project C steel are shown in Fig. 19. Of the curves reported[16] for the ¾-in. plates, the one chosen for subsequent correlation studies apparently does coincide with the Charpy V curve for project A steel, but it does not represent the average curve for the various C steel plates. Hence, any conclusions regarding the inadequacies of Charpy V tests based on A and C comparisons are questionable. In the case of the

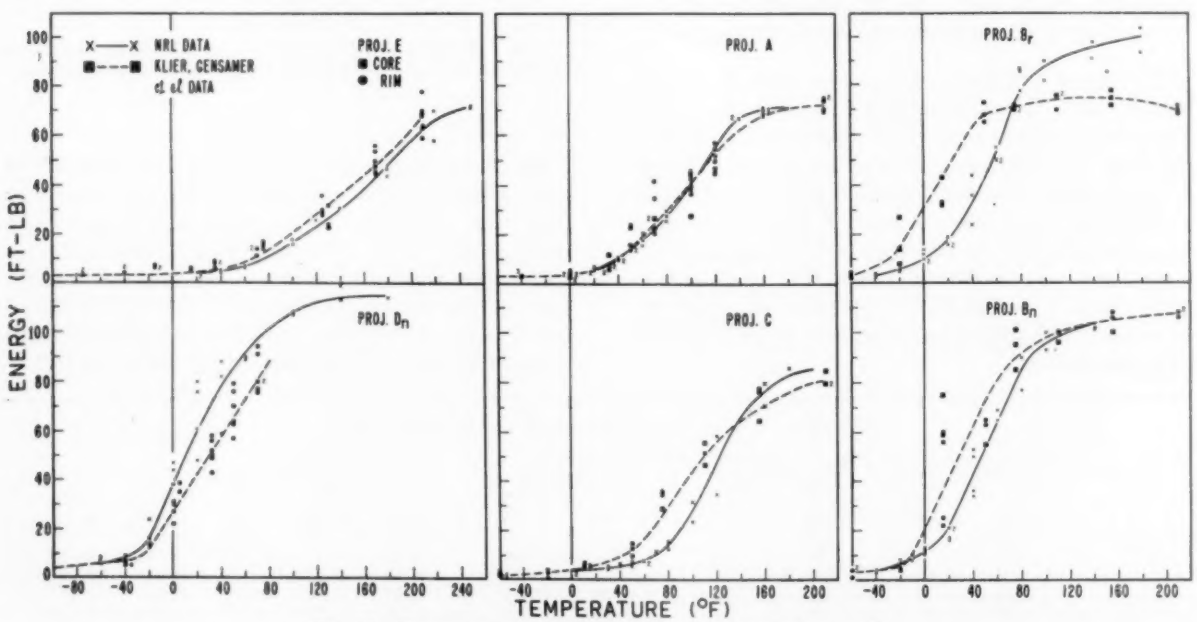

Fig. 18 Comparison of Charpy V data for six project steels

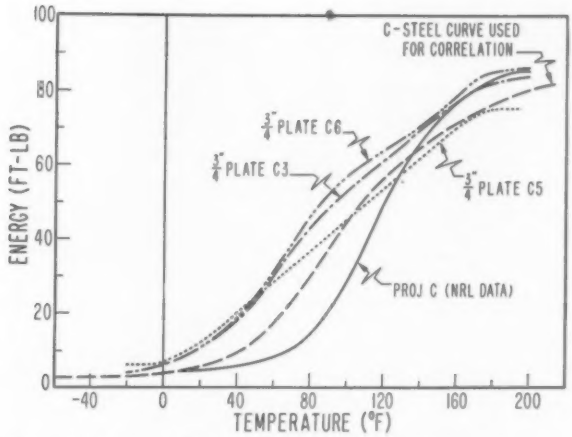

Fig. 19 Various Charpy V energy transition curves reported for Project C (¾-in.) steel

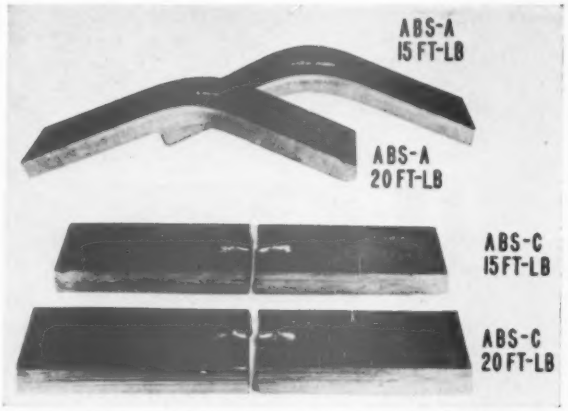

Fig. 20 Drop weight tests of ABS-A and ABS-C steels at temperatures equivalent to Charpy V 15 and 20 ft-lb

Note large ductility reserve in Steel A but not in Steel C. In order to develop extensive deformation in the ABS-C steel it is necessary to test at Charpy V 30 ft-lb temperatures.

NRL tests Charpy V curves were obtained for A and C steels adjacent to the material which was tested by the crack-starter method. The same relative differences were indicated by the Charpy curves as well as by the fracture tests (C at approximately 20° F inferior to A).

Differences in tear test transitions for A and C served as another basis of argument against the Charpy V test.[17] It should be noted that for the C steel the tear test correlates with 60 ft-lb and what is more important this is very near the top of the transition range. In no other case is the tear test correlation so high on the Charpy V curve. Explosion crack-starter tests conducted at temperatures related to the upper portion of the Charpy V transition range have demonstrated *without exception* a near refusal to crack, see Fig. 2.

SUMMARY DISCUSSION

The quest for an ideal specimen for the evaluation of the performance to be expected of a steel in a welded structure such as a ship had led to the development of a great variety of specimens and test procedures. The ideal will probably never be found for even the closest of all possible duplication of the structure (other ships for example) does not always give the same result in service.

Based on Naval Research Laboratory test results it is now apparent that service performance is a question of probabilities—a sharp crack defect at a position of yielding in a steel of inadequate properties at the service temperature involved provides for a high probability for the initiation of failure. If the design is such that yielding is not developed at any position, or if the steel is not sensitive to crack-like defects to the lowest service temperature, failures should not be possible. Design based on the elimination of yield positions should permit the use of steels susceptible to brittle fracture and, similarly, the use of steels which are resistant to brittle fracture should permit the use of designs in which local yielding is anticipated.

The various test procedures which have been developed for the evaluation of the susceptibility of the steel to fracture fall in three groups:

1. Tests of conventional small specimens such as the Charpy V type for which correlation to service is expected to be empirical.
2. Tests of full thickness specimens (such as wide plate tests) utilizing arbitrary machined notches which are expected to correlate directly to service on a basis of fracture appearance (propagation aspects of fracture).
3. Tests of full thickness specimens utilizing ultrasharp cracks considered to be the equivalent to the natural type. For these tests (such as the crack-starter type) it is expected that a direct correlation to service may be attained with respect to ductility and fracture transitions (initiation and propagation aspects of fracture).

The only reliable correlation to service performance now available is in terms of an empirical correlation of Charpy V tests to ship fracture plates obtained by the NBS studies. It is considered significant that the ultrasharp notch, full thickness tests described as the crack-starter tests show the same correlation with Charpy V tests data as the NBS studies with respect to both initiation and propagation limits.

On the basis of these findings the crack-starter tests should be considered of value for the investigation of improved steels for which no service data are available. The findings that crack-starter tests of fully killed steels (such as the ABS-C type) do not correlate with the Charpy V curve in the same manner that the semi-killed and rimmed steels do, present a real problem. While no service data relating to failures of fully killed steel are available it is difficult to ignore the indications of crack-starter tests that the NBS correlation cannot be extended to other types of steels. The fact remains that in the drop weight tests the ABS-A steels may be severely deformed without fracture at temperatures of Charpy V 15 to 20 ft-lb while at the same Charpy levels the ABS-C steels fracture with the application of barely measurable deformation, Fig. 20. The presence of a sharp crack is a realistic assumption for a large

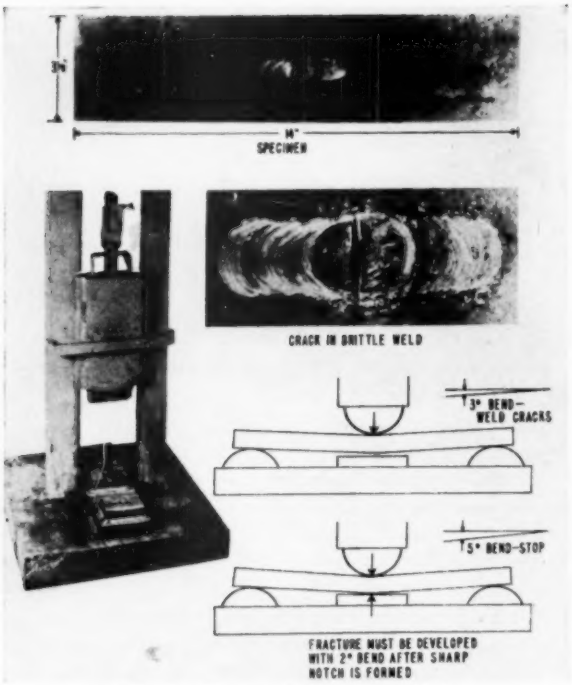

Fig. 1a Drop weight test method

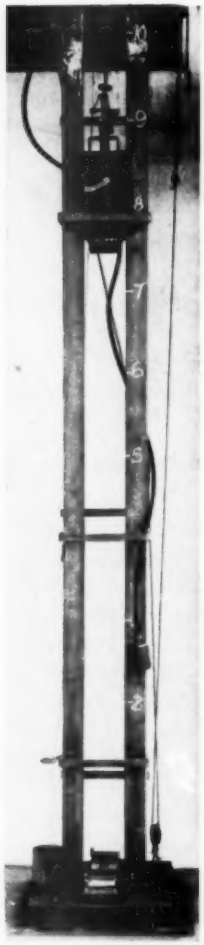

Fig. 2a General view of drop weight test frame

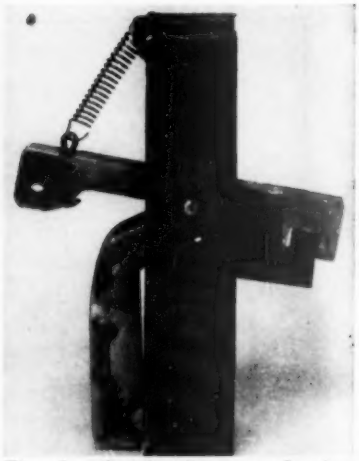

Fig. 3a Quick release mechanism

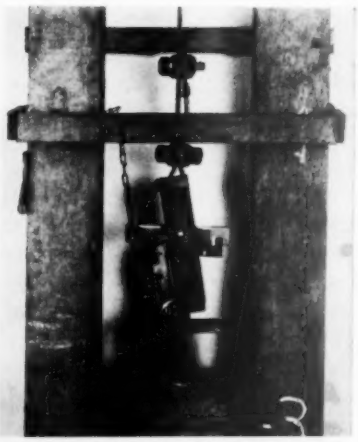

Fig. 4a Release mechanism in support position; a downward pull on the chain causes release of the weight

welded structure, and the development of small amounts of deformation at positions of unfavorable design is also realistic. At 15–20 ft-lb temperatures the ABS-A steel shown in Fig. 20 has a very large ductility reserve but the ABS-C does not.

Additional evidence of differences between semikilled and rimmed steels and fully killed steels is demonstrated by the wide plate tests. The fracture transition of the wide plate tests corresponds to the fracture transition *T–S* of the explosion tests. Like the *T–S* transitions, wide plate transitions of fully killed steels occur at temperatures equivalent to higher Charpy V energy than observed for the semikilled and rimmed steels.

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Appendix

The drop weight test was developed to determine the temperature at which a given steel loses its ability to deform in the presence of a sharp crack-like defect (the worst type to be expected). Figure 1*a* illustrates the specimen and test equipment. The condition of a sharp crack-like flaw is synthesized by the use of a brittle, hard-surfacing type weld. On loading by drop

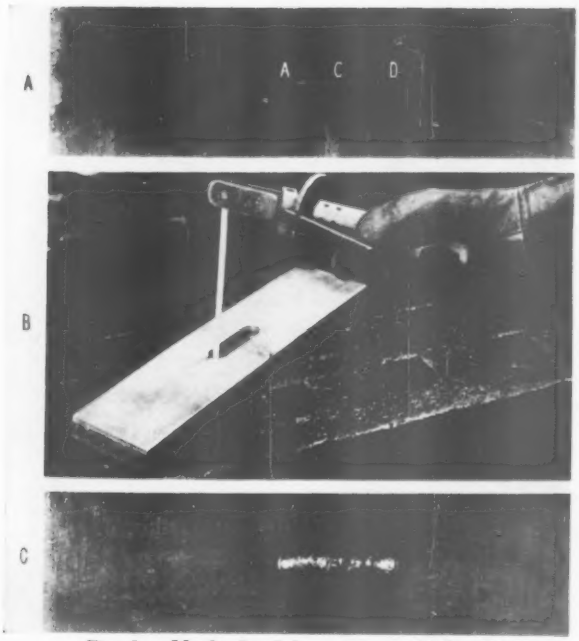

Fig. 5a Methods of depositing weld bead

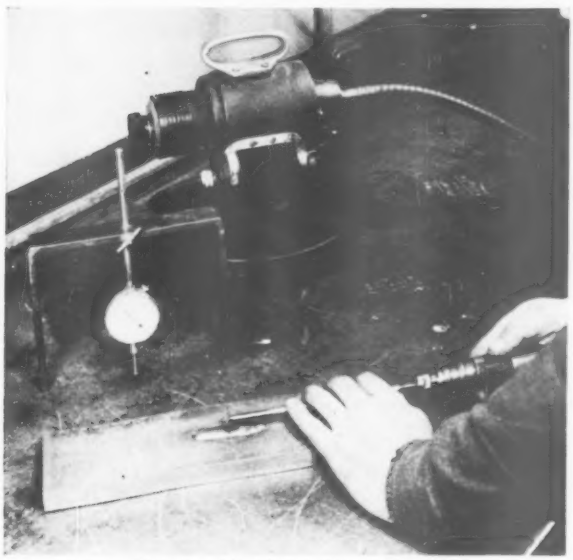

Fig. 6a Notching of weld bead

weight, this weld cracks in a brittle manner thus developing a sharp crack-like defect. As noted (Fig. 1*a*) 3 deg. of bend is required to fracture the weld. By the use of a stop, the total bend is restricted to 5 deg; if the additional 2 deg of bend is not permitted the steel fractures.

THE DROP WEIGHT EQUIPMENT

The drop weight equipment is of simple design based on the use of readily available rolled steel shapes. Figure 2*a* illustrates the complete assembly. The weight release mechanism is illustrated in Figs. 3*a* and 4*a*. The weight is raised by the use of an electric hoist or alternately by the use of a hand crank.

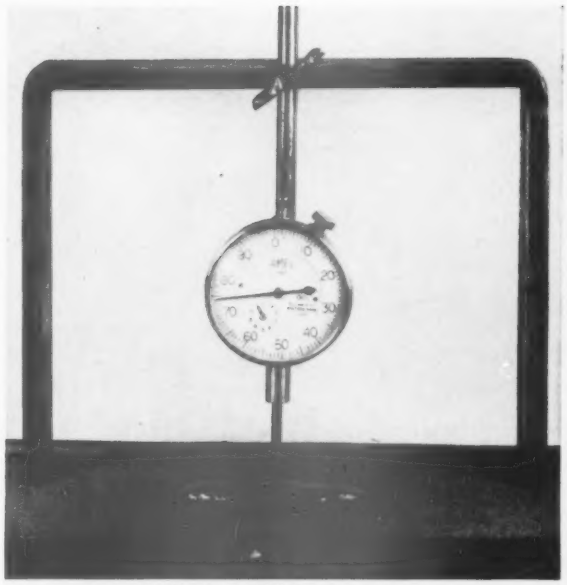

Fig. 7a Thickness gage

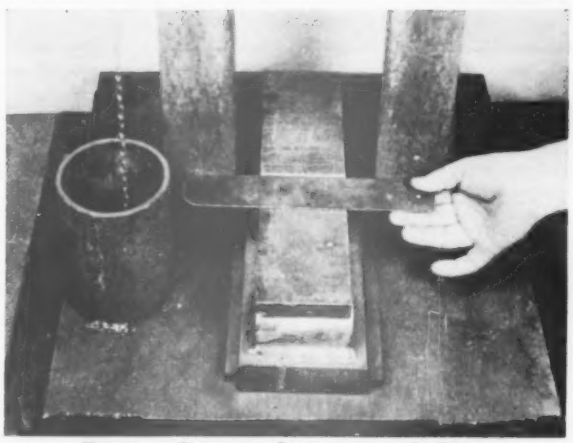

Fig. 8a Alignment by center-scribed line

PREPARATION OF THE DROP WEIGHT SPECIMEN

The drop weight specimen which is T x $3^1/_2$ x 14 in. (T being any thickness up to and including 1 in.) can be either flame or saw cut from plate material. Part *A* of Fig. 5*a* shows the layout detail prior to application of the crack-starting weld bead. The three punch marks assist the welding operator in centering the bead properly on the test piece. Points *A* and *D*, each of which are $1^1/_4$ in. from the center point *C*, are the weld start locations; the terminal point for each half of the weld bead is point *C*. In lieu of the punch layout method for preparing the specimen an alternative system which in many respects is more desirable can be used. A copper template, Part *B* of Fig. 5*a* with an elongated slot at the center, is used to locate the weld bead; the same welding sequence is employed.

Murex Hardex 25, $^3/_{16}$-in. diam electrode, is employed to deposit the weld bead. The deposited weld metal

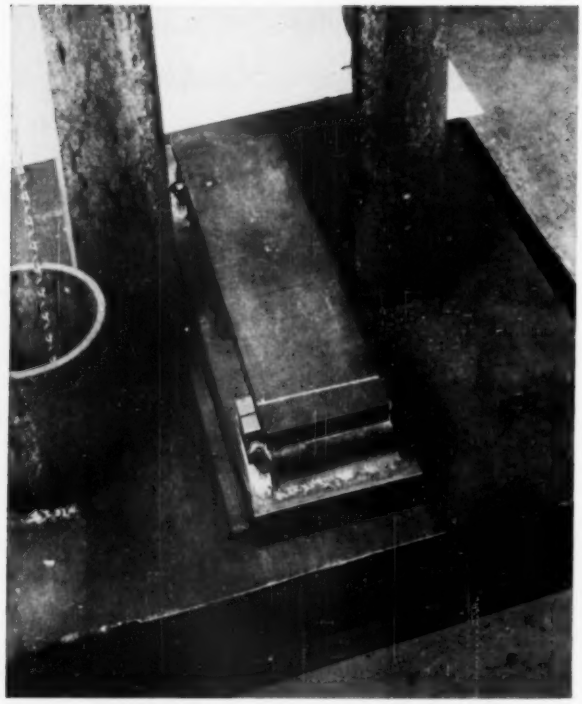

Fig. 9a Alignment by reference mark at support position

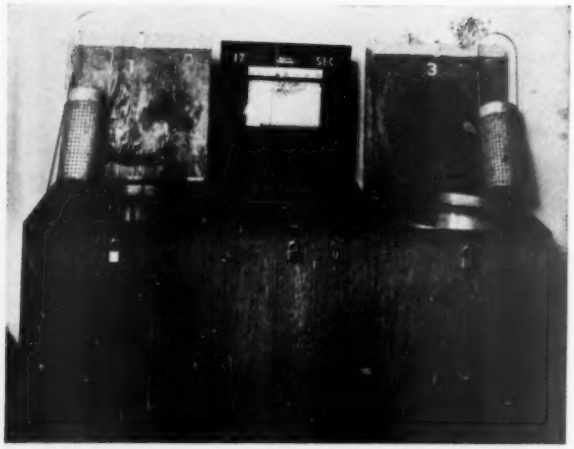

Fig. 10a Equipment for cooling or heating test specimens

Fig. 11a Test of small sample by means of welded ends

is extremely brittle to temperatures as high as 400° F which makes this material well suited for the intended purpose of crack initiation. The bead appearance is determined by the amperage, arc-voltage and speed of travel used; 180 to 200 amp, a medium arc-length and a travel speed which will result in a moderately high-crowned bead have been found to be suitable conditions. An oscillating or weaving motion is unnecessary since this electrode naturally deposits a bead having a width of from $^1/_2$ to $^5/_8$ in. The height of the center crater position should be approximately equal to the height of the bead crown, but any deficiency observed after cleaning the weld can be corrected by adding more metal to the crater depression. The finished crack-starter weld is shown in Part *C* of Fig. 5*a*.

The final preparation of the specimen consists of notching the deposited weld at the center as shown in Fig. 6*a*. A variable speed, flexible-shaft machine is used for this purpose. A thin, 1-in. diam abrasive disk (Ticonium separation disk) on the extended hand-controlled shaft is used for the grinding operation. To reduce abrasive wheel breakage, it is essential that light pressure and a high rotating speed be maintained during this operation. The shaft extension consists of a $^1/_4$-in. rod approximately 10 in. long revolving in a lubricated brass ferrule which permits a hand-grip for easy control and results in a notch which is normal to the surface of the specimen. The abrasive disk is retained on the end of the shaft by means of a small machine screw.

The depth of the notch is not maintained at a specific dimension. Instead of measuring the depth of the notch referenced from the crown of the weld, the thickness of the remaining weld under the notch has been arbitrarily standardized at 0.070 in. with a plus 0.010 in. tolerance. The 0.070 in. thickness is maintained across the width of the weld. This is easily accomplished by a slight back and forth motion of the cutting disk.

Figure 7*a* illustrates the method for measuring the thickness of weld metal at the bottom of the notch. The adjustable dial gage with bridge support is used in the following manner: (1) the dial is adjusted to the zero setting while resting in position on the specimen so that the pointer contacts the plate surface; (2) the bridge is moved to a location directly over the weld with the pointer resting in the notch; (3) the dial now reads the thickness of weld metal under the notch. With experience in the preparation of a few specimens the instrument needs only to be used in the final checking of the finished notch. Actually, the height of the remaining weld metal is not critical—all that is necessary is to ensure that the notch is not cut so as to contact the plate.

To facilitate the alignment of the specimen on the anvil of the drop weight machine, a line is scribed (a yellow wax pencil is suitable for this purpose) on the unwelded surface opposite to the notch. When the specimen is placed on the anvil for testing this scribed line serves as reference mark for aligning the notch directly under the impact point of the tup, Fig. 8*a*. Alternately, a scribed line located and referenced as shown in Fig. 9*a* may be used.

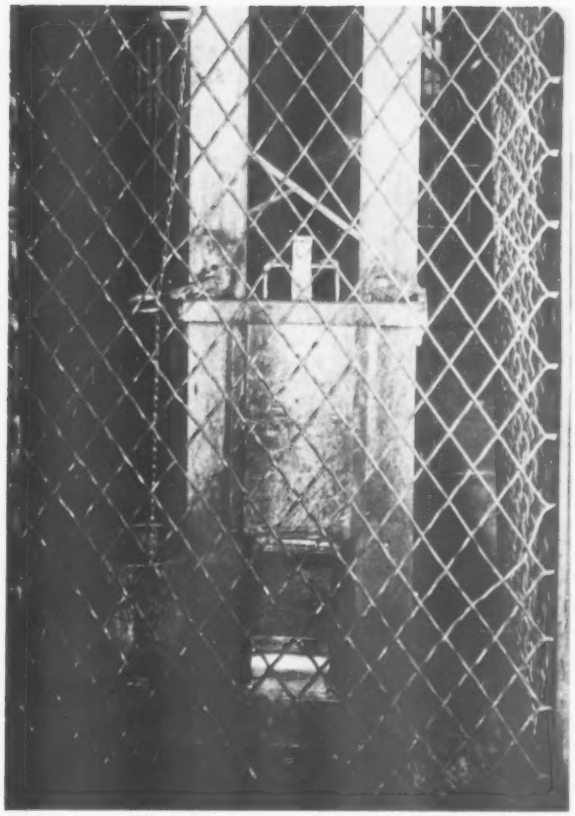

Fig. 12a Back view of protection guard—the front remains open to the operator

TESTING PROCEDURE

Figure 10*a* shows a system for cooling or heating the test specimens to the desired testing temperature. Each plywood box contains a cylindrical, light-gage metal tank which has been surrounded with 4 in. of vermiculite insulation. The tall, perforated-metal baskets are filled with pieces of dry ice and immersed in and out of the denatured alcohol bath which covers the specimens (as many as 8–10 specimens of various materials may be cooled at the same time). Adjustment of the temperature may be made during the 30 to 45 min. hold period required for equalization of the specimens. The combination of a multipoint temperature recorder and thermocouples is a convenient and accurate method of temperature recording; however, immersion thermometers may also be employed. Testing temperatures as low as −100° F can be attained with this or similar equipment. Temperatures above ambient are attained by means of immersion heaters in water or light oil depending on the temperature. Approximately 10 sec elapses between removal of the specimen from the bath and the completion of testing. This delay does not significantly affect the temperature of the specimen.

The usual tests sequence is as follows: (1) Estimate the approximate fracture temperature, then test in 20° F steps (0, 20, 40° F would be a good series for a mild steel). (2) When the approximate fracture temperature is established (assume specimens at 0 and 20° F broke but 40° F did not) test in duplicate in 10° F intervals above the highest fracture temperature, i.e., +30 and +40° F for this example. It will be found that initially 6–8 specimens are required; with experience it is possible to cut the number to a minimum of six. If material is not sufficient, ends may be welded to samples as small as $3^1/_2$ x 4 in., Fig. 11*a*. By this procedure three tests may be made from one $3^1/_2$-x 14-in. test sample, i.e., after the first test the two halves are assembled as shown in the figure and two more tests are made.

Table 1A—Drop Heights (60-Lb Weight) For Various Materials—12-In. Support Span

Materials	*Tensile strength, psi*	*Thickness, in.*	*Height, ft.*
Mild steel	60,000	1/2	6
		3/4	8
		1	10
Alloy steel	125,000	1/2	8
		3/4	10
		1	14
	150,000	1/2	10

The design of the machine permits varying the height from which the weight is dropped. This is necessary for testing materials of various thicknesses and tensile strengths. The height at which the weight should be set for a specific material is determined by preliminary room temperature tests using various heights and observing the minimum height which develops full deflection of the specimen as indicated by contact against the stop block of the anvil. After determining the minimum height an additional one or two feet are added and this height is used for subsequent tests at all temperatures. Since the height which is necessary to produce contact with the stop is directly related to the tensile strength of the material, it follows that any material of similar stength can be tested in a like manner providing its nominal thickness is the same. It is suggested that a height record of test materials be maintained as a guide for testing similar materials. Table 1A provides a listing of heights used from various materials.

High-strength materials, in particular, often fly outward on breaking. A removable metal guard shown in Fig. 12*a* serves as protection from flying pieces.

Metallurgical Aspects of Welding Precipitation-Hardening Stainless Steels

Response of welded joints to heat treatments and effects of such treatments and weld defects on mechanical properties

by C. W. Funk and M. J. Granger

Abstract

Aircraft materials of construction are compared with respect to yield strength to weight ratio at ambient and elevated temperatures, corrosion resistance and characteristics during fabrication. Mechanical properties and structural changes are discussed for four types of stainless steels—Stainless W, 17–7PH, 17–4PH and V2B. The microstructure is discussed in conjunction with its response to alloying elements and heat treatment as well as its effect on mechanical properties. The mechanisms and procedures of annealing, transformation and precipitation-hardening are discussed relative to improved ductility in welded joints. Observations at Aerojet-General Corp. include a chemical analysis of weldments, studies of porosity, abnormalities in the heat-affected zone and nonfusion effects. It is believed that porosity in welds is due to entrapped gas, which may originate either from excess water vapor carried in the shielding gases or from evolution of dissolved gas from the parent metal. The chemical composition of 17–7PH, and particularly its high aluminum content, is responsible for nonfusion defects, while variation of the composition greatly influences the response of the alloy to heat treatment.

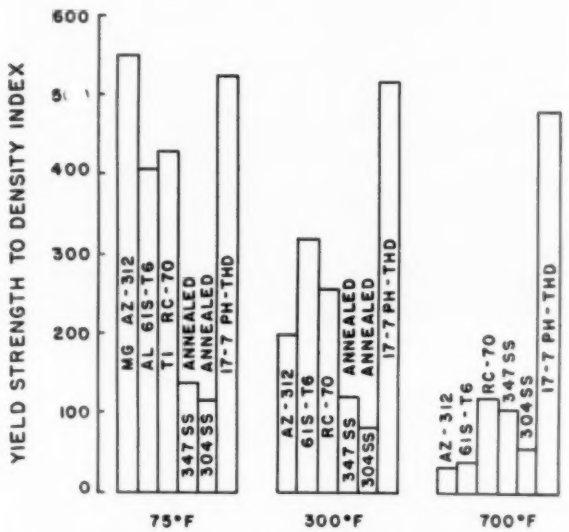

Fig. 1 Comparison of yield-strength to weight ratios for typical aircraft structural alloys[8, 11]

INTRODUCTION

THE design and fabrication of air-borne equipment requires the use of materials with high strength-to-weight ratios. This principle holds true for the construction of liquid-propellant rocket power plants, with the additional requisites of ductility, high-temperature serviceability, and resistance to corrosive environments. Fabrication adds limitations of availability of sheet form, weldability and formability. Because Aerojet-General production units are usually limited to pressure-tight assemblies requiring welding and exposure to corrosive propellants and strength at elevated temperatures, the 400 series of heat-treatable stainless steels, the commercially available titanium alloys, and the higher-strength aluminum alloys have been excluded from this discussion as not amenable to these fabrication and corrosion requirements. Cold-worked stainless steels also have been omitted because of their strength loss in welded joints.

Because units are usually designed on the basis of yield strength at 0.2% offset rather than ultimate strength, evaluation of the yield strength to weight ratio provides a more accurate comparison of the relative efficiency of materials. In Fig. 1 the design yield strength to weight ratio is compared for several alloys selected as typical of their classes at three operating temperatures.[1] At ambient temperatures the light alloys exhibit marked advantages as a result of their low density and improved stress levels introduced by alloying and heat treatment. Annealed titanium shows the disadvantage of higher density. Only the heat-treatable stainless steels are competitive at room temperature.

Operation at 300° F shows a one-third to two-thirds loss of the yield strength to weight ratio for the light metals and titanium. Precipitation-hardened stainless steel assumes a dominant position at 300° F by a minor loss of the yield strength to weight ratio. Comparison

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Scheduled for presentation at the Thirty-Fifth AWS National Fall Meeting to be held in Chicago, Ill., Nov. 1-5, 1954.

Table 1—Chemical Analyses of Precipitation-Hardening Stainless Steels[13]

	Analyses, wt %			
Element	Stainless W	17-4PH	17-7PH	V2B
C	0.06	0.07 max	0.09 max	<0.07
Mn	0.54	1.00 max	1.00 max	0.50-0.75
P	0.016	0.04 max	0.04 max	...
S	0.016	0.03 max	0.03 max	...
Si	0.58	1.00 max	1.00 max	2.25-3.25
Ni	7.28	3.00-5.00	6.50-7.75	9.75-10.25
Cr	17.60	15.50-17.50	16-18.00	19-19.5
Ti	0.90	...	...	...
Al	0.17	...	0.75-1.50	...
Mo	...	...	...	3.0-3.5
Be	...	...	...	0.10-0.20
Cu	...	3.00-4.00	...	...
Cb-Ta	...	0.25-0.45	...	...

indicates that the precipitation-hardening stainless steel is more than twice as efficient as its nearest competitor, commercial titanium. Annealed stainless steel exhibits only a relatively minor gain in the yield strength to weight ratio at 300° F.

At 700° F the light metals lose about 90% of their effectiveness, and titanium loses about 70% of its strength. Although annealed stainless steels maintain the same yield strength to weight ratios as found at room temperature, they are low because of low strength and high density. The fourfold advantage that precipitation-hardening stainless steel has maintained over its nearest competitor at the high temperature level is especially significant.

PRECIPITATION-HARDENING STAINLESS STEELS

This class of alloy includes those steels containing sufficient chromium to provide complete passivation in severely corrosive environments, sufficient nickel to produce predominantly an austenitic microstructure in the annealed condition, and a sufficient amount of a third element to form a hardening constituent to provide strength increases by a precipitation mechanism. All of these alloys must be heat treated in a similar manner to obtain the high strengths of which they are capable. This requires that the metal be heated to a relatively high temperature for solution of the hardening agent and cooled rapidly to produce a supersaturated solid solution, and reheated to a lower temperature to allow controlled precipitation of the hardening agent.

The first commercially available precipitation-hardening stainless steel for structural use was reported by Smith, Wyche and Gorr in 1946.[2] This material was recorded as "Stainless W" by the U. S. Steel Corp. As shown in Table 1, the analysis approached that of 18–8 steel, with 0.7% titanium as a hardening agent and ferrite former. Although a wide range of heat treatments was available, a treatment comparable to that used for similar alloys was selected in order to compare the mechanical properties. The strengths obtained were similar to those of other precipitation-hardening stainless steels. The ductility, which varies over a wide range, is appreciably less than for other grades, and may be a contributing factor to the limited application of this material on the commercial market.

Two grades of precipitation-hardening alloys, 17–7PH and 17–4PH, were announced by Goller and Clarke of the Armco Steel Corp. in 1950.[3] In analysis, 17–4PH steel approaches an 18–8 type, and uses 4% copper as a hardening agent and corrosion inhibitor. The strengths achieved through this treatment range from 180 to 210 ksi ultimate stress and 165 to 200 ksi for yield stress at 0.2% offset. The elongation is considerably improved

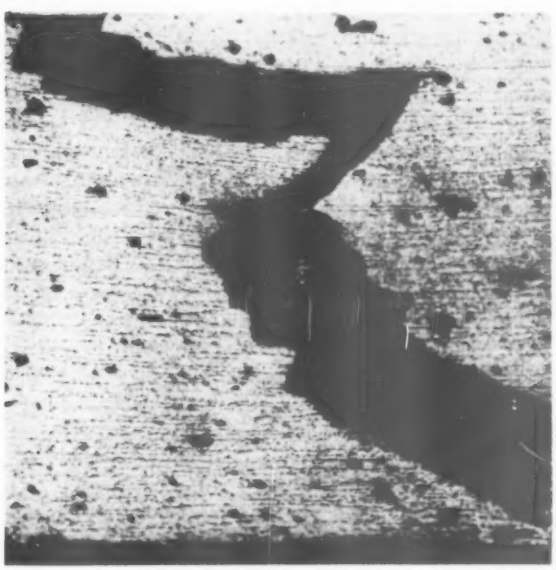

Fig. 2a

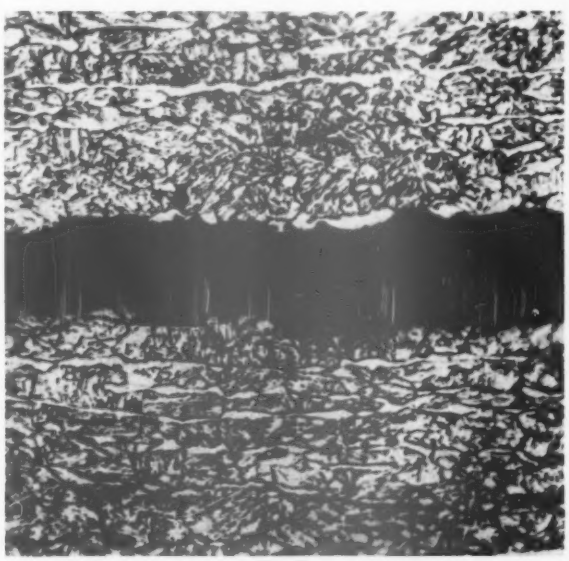

Fig. 2b

Fig. 2 Splitting of 0.125-in. plate along ferrite laminations during bending in THD condition. Magnification: Fig. 2a, × 100; Fig. 2b, × 500

over that of "Stainless W," and ranges from 6 to 15% in a 2-in. gage length. Good corrosion resistance, freedom from intergranular attack, and dimensional stability during heat treatment are additional features of the alloy. Its availability is limited to castings, forgings, wrought bar, wire and coated electrodes, because its partially hardened condition reduces its workability.

The second of the Armco alloys, 17–7PH, has an analysis similar to that of 18–8 steel, plus the addition of 1.1% aluminum. The 17–7PH alloy is distinguished from other precipitation-hardening alloys by the requirement for an intermediate heat treatment followed by cooling to 60° F. Aerojet-General deviates from the precipitation-hardening practice to use a higher aging temperature for improved ductility. The mechanical properties and corrosion resistance are very similar to those of 17–4PH, with slightly improved ductility. This material is available as rolled sheet, forgings, wrought bar and wire. A major disadvantage of 17–4 and 17–7PH is anisotropy caused by delta ferrite stringers; this results in only a minor loss of transverse strength, but strength and ductility in the direction normal to the surface of the sheet are believed to be appreciably reduced. This is confirmed by observation of failures in which plate stock has been split, as shown in Figs. 2*a* and 2*b*, and by reported weakness of collar-button test specimens of the material.

The most recent addition to the commercially available stainless steels is an alloy designated as V2B, reported in 1953 by N. F. Mott.[4] The analysis shows that 0.1 to 0.2% beryllium is utilized as a hardening agent. The chromium and nickel contents are appreciably higher than used in the other alloys considered. The alloy is unique in that it is reportedly not subject to overaging. The mechanical properties are inferior to those of the other alloys considered with respect to ductility probably because of the cast structure. Development of wrought products may improve these characteristics. Although good corrosion resistance is reported for most mineral acids, it is less satisfactory in nitric acids.[4]

EFFECT OF ALLOY CONTENT ON STRUCTURE

The distinguishing feature of precipitation-hardening alloys is the ability of the materials to increase their strength and hardness through heat treatment. The common types of chromium-nickel stainless steels can be hardened only through cold-working, and although fairly high strengths are obtainable by this method, this strength is lost in a welded joint and cannot be recovered. The precipitation-hardening alloys have an advantage over the cold-worked steels in that it is possible to perform intricate drawing and forming operations under soft annealed conditions, after which they may be heat treated to high strength.

The reactions involved in the heat treatment of these alloys are complex and are not yet completely understood. It has been established through the work of Smith, Wyche, and Gorr[2] that precipitation-hardening

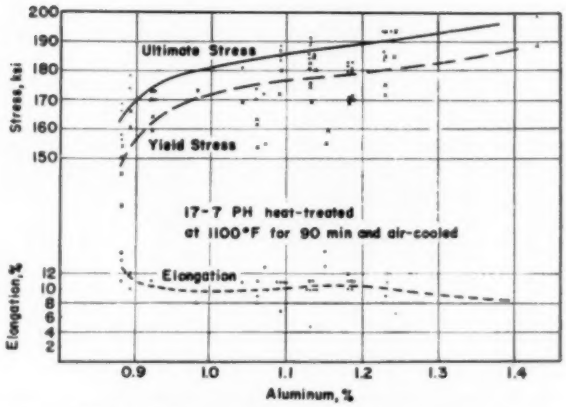

Fig. 3 Effect of aluminum content on mechanical properties of 17–7PH stainless steel

in the subject alloys can only occur in body-centered cubic iron, which is the crystal structure of ferrite or martensite. Alloys of the 18Cr–8Ni type are normally face-centered cubic austenitic in the annealed condition. It becomes apparent that the analysis of the material must be so balanced or heat treatment conducted in such a way that a transformation of face-centered cubic to body-centered cubic occurs during cooling from elevated solution treating temperatures, simultaneously retaining the hardening agent in solid solution. The hardener may be any of several elements but must be soluble in austenite and insoluble in ferrite. Heating to a temperature below that required for the ferrite to austenite transformation permits precipitation of the hardening phase.[5] This precipitate is reported to be visible with the electron microscope in some instances, but its exact identity is questionable at present. In the case of 17–7PH it is assumed that the precipitate is an Al-Ni compound,[3] for 17–4PH a dispersed copper-rich phase,[2] and in the case of V2B a complex beryllide is believed to be the precipitate.[4]

Factors for 17–7PH austenite-ferrite balance have been broadly established for limits within which the material will respond to heat treatment. The 17–7PH balanced analysis must be disturbed by an intermediate heat treatment to initiate the transformation of austenite to ferrite, but the other precipitation-hardening alloys transform during cooling from the solution temperature. In the instance of 17–7PH the intermediate heat treatment permits precipitation of carbides, which decreases the stability of the austenite, so that cooling to 60° F causes a martensitic type of transformation. All the other analyses are adjusted with unbalanced composition, so that transformation occurs on cooling from the solution annealing temperature. Once ferrite is formed, precipitation-hardening becomes possible. The precipitating phase is in supersaturated solid solution immediately after the martensitic transformation. Reheating to the range of 700 to 1200° F produces precipitation that results in increasing strength and hardness, while elongation remains constant or increases slightly. It can be seen

Table 2—Chemical Analyses and M_s Temperatures

Material	Concentration, wt. % C	Mn	Si	Ni	Cr	Ti	Al	N_2	Cb	Ferrite Annealed	Rockwell hardness Annealed	Rockwell hardness Aged	M_s calcd., ° F From analysis
Smith, Wyche and Gorr Heat													
223	0.06	0.45	0.60	9.56	17.40	0.66	...	...	...	15	B68	B71	−273
281	0.06	0.57	0.64	9.12	17.60	0.84	0.19	0.015	...	25	B71	B76	−247
280	0.05	0.55	0.70	8.24	18.68	0.88	0.22	0.018	...	25	B81	B89	−202
278	0.08	0.62	0.69	7.10	18.52	0.84	0.22	0.030	...	35	B84	B92	−191
265	0.06	0.62	0.57	7.60	17.04	0.85	0.21	0.033	...	75	C20	C32	−70
283	0.07	0.55	0.56	6.93	16.88	...	0.22	0.054	1.13	85	C26	C26	−67
275	0.06	0.61	0.57	5.84	17.24	0.88	0.19	0.022	...	100	C27	C45	+142
244	0.06	0.54	0.58	7.28	17.60	0.90	0.17	0.013	...	100	C26	C45	−10
17–7PH (nom)*	0.07	(0.75)	(0.45)	7	17	...	1.10	...	...	...	B80	C30–45	0
17–4PH (nom)*	0.04	(0.75)	(0.45)	3.75	16.5	...	3.75 Cu	...	...	...	C38	C40–45	+484
V2B (nom)	0.07	3.00	3.00	10.00	19.25	...	2.12 Cu	3.25 Mo	15 Be	..	C28	C39	−619

* Manganese and silicon quantities selected as typical. $M_s = 75(14.6 - Cr) + 110(8.9 - Ni) + 60(1.33 - Mn) + 50(0.47 - Si) + 3000(0.068 - [C + N])$. Eichelman and Hull formula.

that the hardening response during aging is similar for these alloys to that of other common precipitation-hardening materials such as the aluminum alloys and copper beryllium alloys. Nominally, 17–7PH contains 1.1% aluminum, but experience has shown that the amount of this element can vary from about 0.84 to 1.2%. This variation in aluminum content apparently affects the mechanical properties of the heat-treated material; it is, therefore, required at Aerojet-General that all materials used in a critical unit have aluminum contents within 0.2% of each other. The effect of the variation in aluminum content on ultimate stress, yield stress, and elongation is shown in Fig. 3.

Perhaps the most logical explanation of the process of transformation can be made by consideration of the M_s temperature (temperature of initial martensite formation on cooling) and its variation during heat treatment.[6,7] Table 2 shows the variation of the M_s temperature for the data of Smith *et al.*,[2] as well as the M_s temperatures calculated for 17–4PH and 17–7PH from the formula of Eichelman and Hull.[1] The correlation between hardness data and M_s temperature appears to be quite consistent. The attempt to show this correlation is very recent and further work is in progress at Aerojet toward its development. If a relationship can be shown between the M_s temperature and the response to heat treatment of these alloys, a valuable tool would be available for control of properties after heat treatment.

The magnetic permeability of annealed 17–7PH is very similar to that of the common austenitic alloys, while transformation to ferrite makes the material magnetic. The magnetic permeability can be used as a tool to follow the extent of transformation introduced by cold work on annealed material. All of the other alloys considered in this paper are magnetic under all conditions at room temperature.

Standard heat-treating equipment is usable with all these materials. Hydrogen or cracked ammonia atmospheres are necessary for best surface protection,[8] and salt-bath heat treatment equipment is also satisfactory in most cases. Caution should be exerted in using protective gas atmospheres which contain carbon monoxide or carbon dioxide. Such atmospheres are commonly used for heat treating low-alloy steels. The danger involved in using them for stainless steels arises from the great propensity of these materials to absorb carbon at elevated temperatures. This results in a stabilized austenitic composition, preventing hardening of the material by the austenite to ferrite transformation.

ANNEALING OF 17–7PH

Stress-relief annealing is required between forming operations when working with wrought materials, annealing for homogenization is necessary prior to hardening and postweld annealing is required to remove the heterogeneous structure areas from the welding joint. Cold work during forming operations introduces transformation of austenite to ferrite with resultant hardening in the case of 17–7PH.

The temperatures required for annealing these steels are listed in Table 3. It is apparent the annealing

Table 3—Characteristics of Precipitation Hardening Stainless Steels[12]

Alloy	Condition	Hardener	Heat treatment Temp, ° F	Time, min.	Quench	Mechanical properties Yield, ksi	Ult., ksi	Elong., %	Hardness Rockwell
Stainless W*	Annealed	0.7% Ti	1900	30	Air	75	120	3–10	..
Stainless W*	Aged	0.7% Ti	950	30	Air	180	195	3–10	..
17–4PH†	A	4% Cu	1900	30	Air	110	150	6–15	..
17–4PH†	H 1100	4% Cu	1100	240	Air	140	150	17	C35
17–7PH†	A	1.1% Al	1950	30	Air	40	130	30	B85
17–7PH†	T	1.1% Al	1400	90	Air	100	145	9	C31
17–7PH†	TH 950	1.1% Al	950	90	Air	200	215	8	C45
17–7PH†	TH 1050	1.1% Al	1050	90	Air	185	200	9	C43
V2B*	Annealed	0.15% Be	2000	..	Air	..	..	...	C28
V2B*	Hardened	0.15% Be	925	480	Air	122	151	3	C39

* Poor corrosion resistance in fuming nitric acid.
† Good corrosion resistance in fuming nitric acid.

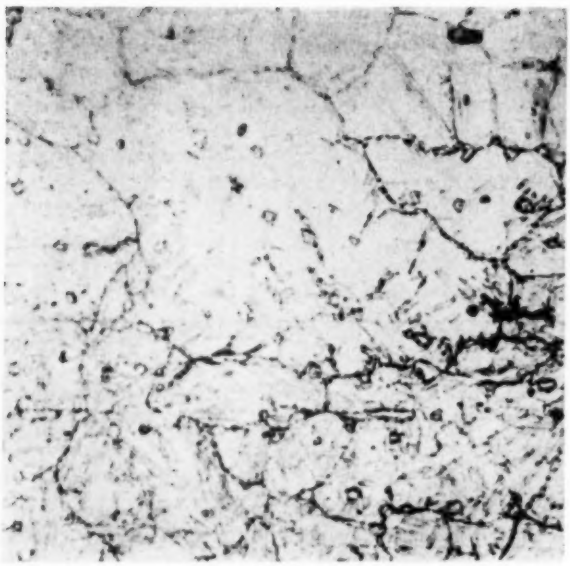

Fig. 4a

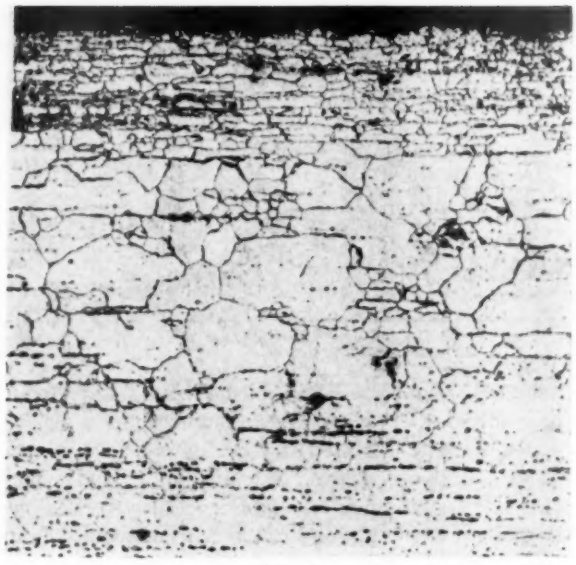

Fig. 4b

Fig. 4 Absence of transformed structure due to carbon pickup. Magnification: Fig. 4a, × 750; Fig. 4b, × 100

range is similar to that encountered with other chromium-nickel alloys. Caution should be exercised in the use of extremely high annealing temperatures, since overheating will increase the amount of delta ferrite and will coarsen the grain size of these materials. Cooling from the annealing temperature may be done in air, oil or water. A rapid quench is usually suggested in literature on the subject, but intricate assemblies are usually air-cooled at Aerojet-General to minimize distortion resulting from uneven cooling. Air cooling causes scaling, which in some cases may be difficult to remove. Cracked ammonia, argon and hydrogen are preferable atmospheres for use in annealing, but salt baths have been used successfully in the past and are best for some parts. Regardless of the method of heating used, carbon pickup must be prevented, since this stabilizes the surface material and prevents hardening as shown in Figs. 4*a* and 4*b*. Carbon pickup also is reported to result in a scale which is difficult to remove. The mechanical properties of these materials in the annealed condition are listed in Table 3.

INTERMEDIATE HEAT TREATMENT FOR TRANSFORMATION OF 17-7PH

Transformation heat treatment is required only for 17–7PH, because the annealed, solution-treated material is essentially austenite. The other alloys under consideration are principally ferrite as annealed. Aging does not occur when the hardening agent is dissolved in austenite; consequently, intermediate heat treatment produces an austenite to ferrite phase change upon cooling. Since precipitation-hardening occurs only in ferrite, transformation must precede precipitation. This same result can be accomplished by a subzero treatment or by cold working. Both these methods will produce the same austenite to ferrite transformation as the intermediate treatment at 1400° F.

The austenite to ferrite transformation in 17–7PH is believed to involve the precipitation of chromium carbide noticeable in Fig. 5, which disturbs the austenitic balance so that upon cooling, a transformation to ferrite can occur. This transformation begins at about 200° F and is essentially completed when the material has cooled to 60° F. It is important that the material be cooled to 60° F if uniform properties are to result after aging. If the M_s temperature is low in a given heat, cooling to 60° F may form only 50% ferrite. Since age-hardening will not occur in untransformed austenite, material which is only partly transformed will not be susceptible to complete hardening during aging.

The transformation cycle in the heat treatment of 17–7PH usually requires heating to 1400° F for 90 min. The actual possible temperature range is from 1100 to 1700° F. The holding time within this temperature range can vary from 0.5 to 3 hr depending on the temperature selected. After holding for a sufficient period of time, the material is then cooled to at least 60° F. Recent data are available which indicate that the time delay in cooling the part from 1400 to 60° F should be as short as possible.[9] The maximum time delay appears to be about 1 to 2 hr. The holding time at 60° F should be at least 30 min. If maximum strengths are to be obtained through heat treatment it is important that these two factors be closely controlled. The furnace atmospheres recommended for this intermediate heat treatment are the same as those recommended for best annealing practices. Satisfactory results have been obtained using all of the various methods. The danger of carbon pickup at this temperature is naturally much less than during annealing.

The mechanical and physical properties of 17–7PH in the transformed conditions are listed in Table 3. Transformation causes a dimensional expansion amounting to an increase of 0.004 in./in. Thus, it is advisable either to allow for this expansion or to finish-machine

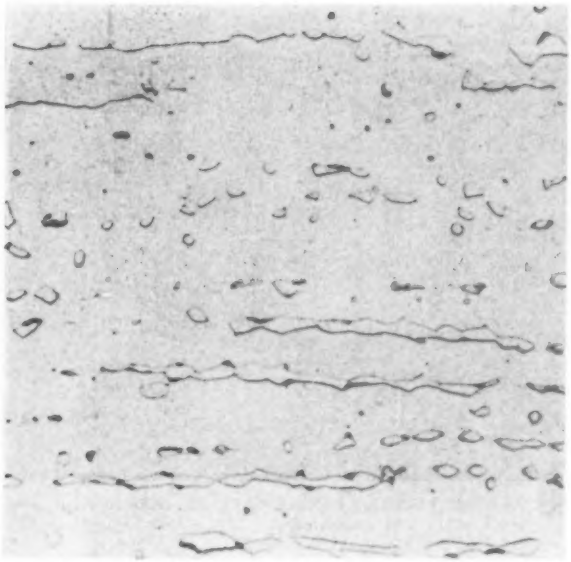

Fig. 5a Microstructure of 17–7PH stainless steel annealed at 1950° F showing delta ferrite stringers and matrix of austenite.[12] *× 750*

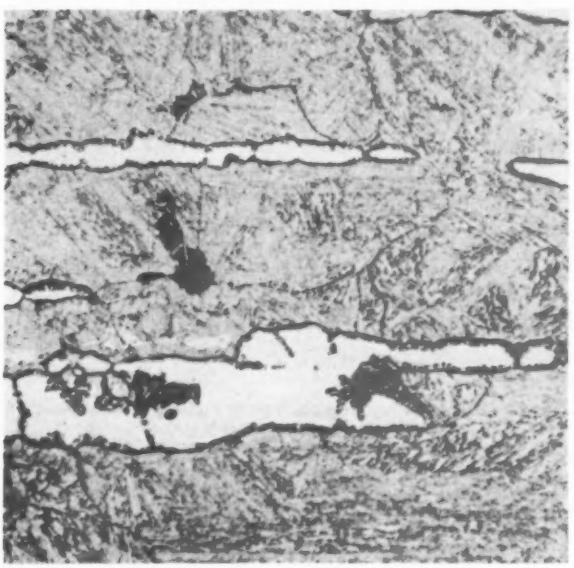

Fig. 5b Microstructure of 17–7PH stainless steel aged at 1100° F showing precipitated carbides in delta ferrite and matrix of ferritic transformation product. × 750

subsequent to transformation heat treatment. The second important factor is that the corrosion resistance of this material is lowest in the transformed condition. If best corrosion-resistance is required, it is advisable either to use the material in the annealed condition or to conduct an aging heat treatment subsequent to transformation.

PRECIPITATION-HARDENING HEAT TREATMENT

If these materials, after a solution heat treatment, followed by transformation heat treatment in the case

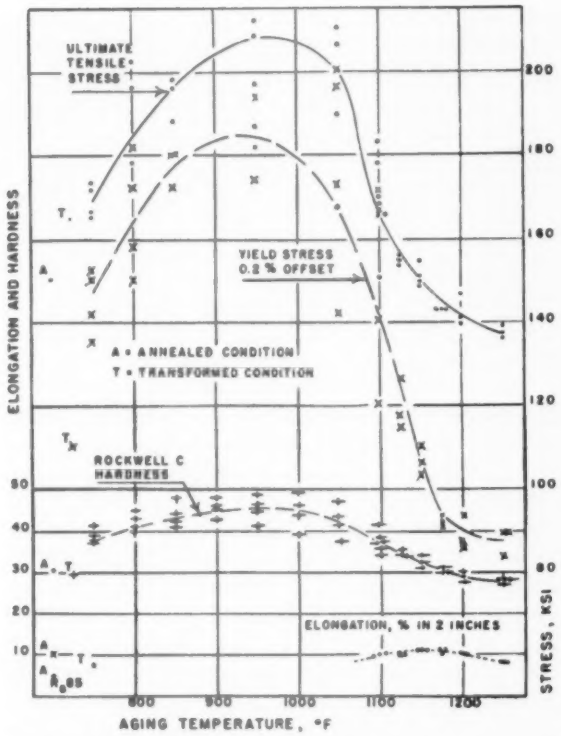

Fig. 6 Effect of aging temperature on typical mechanical properties of 3 heats of 17–7PH stainless steel

of 17–7PH, are heated to temperatures within the range from 900 to 1100° F, age-hardening will occur, increasing the strength of these materials. The times required for this heat treatment range from 1 to 8 hr. The V2B alloy requires the longest aging time, 8 hr at 950° F. The others may be aged for 0.5 to 1.5 hr. Aging of 17–7PH results in a minor contraction amounting to 0.0005 in./in. The precipitation heat treatment permits the particular hardener for each alloy to precipitate from the unstable, supersaturated alpha phase which has been established through prior heat treatment. Table 3 lists the properties of these alloys after aging. All these alloys have very high strengths and correspondingly low elongation. The low elongation of V2B may be attributed partly to the cast structure; attempts to improve the elongation of the other alloys have not been successful without greatly decreasing the strength of the material At Aerojet-General the recommended aging temperature of 1050° F is not used; experience has shown that the resulting ductility is insufficient for highly stressed, welded structures. Instead, an aging temperature of 1100° F is used with ductility slightly increased and the strength considerably lower than that of the material aged at 1050° F. See Fig. 6. This treatment has been found to be necessary in order to obtain satisfactory parts.

WELDING PRECIPITATION-HARDENING STAINLESS STEELS

Although each of the alloys is reported to be weld-

Table 4—Spectrographic Analyses of 17–7PH Weld Products

	Composition, wt. %				
	White deposit	*Black deposit*	*Parent metal*	*Filler wire*	*Weld deposit*
Cr	21.0	41.0	17.1	16.7	17.3
Ni	5.1	7.0	7.1	7.2	7.35
Si	0.69	3.1	0.31	0.58	0.31
Mn	0.46	1.6	0.65	0.80	0.62
Al	9.5	15.0	1.24	1.08	1.02
C	...	...	0.09	0.065	0.04
Fe	43.0	29.0			
Cr_2O_3	38.2	53.5			
NiO	4.1	4.0			
Al_2O_3	22.5	25.5			
FeO	35	17			

able, the authors' experience has been chiefly limited to 17–7PH in sheet metal applications, and this discussion will be limited to the more frequently encountered difficulties.

The 17–7PH grade can be welded by any of the arc and resistance techniques with reasonable joint properties if oxidation and loss of aluminum are avoided during the fusion. Although preheating has not been found to be necessary to prevent cracking, postweld annealing has been used by the authors to improve the ductility of the weld joint. The low carbon content prevents cracking caused by the formation of martensite, and cold cracking is avoided by austenite formed adjacent to the fusion zone that remains austenite upon cooling to room temperature. Hot cracking is minimized by the presence of ferrite in the austenitic microstructure. The inert-gas tungsten-arc process may use helium or argon to prevent oxidation of the aluminum, formation of slag and loss of aluminum from the chemical balance. Use of 17–7PH filler wire requires the inert-gas-shielded arc process because electrode coatings cannot prevent alumina loss. Addition of aluminum to the flux adversely affects the chemical balance of the weld joint. Metallic arc welding may use 17–4PH filler wire for joining 17–7PH if care is taken to dilute the bead sufficiently with the parent metal, which provides a response to the double heat treatment required to obtain suitable strength from the 17–7PH.

ANALYSIS OF 17–7PH WELD DEPOSITS

Because the chemical analysis of 17–7PH steel has been shown to have significant effects on its metallographic structure and mechanical properties, some consideration has been given to the effect of the inert-gas-shielded arc on the chemical analysis of the weld joint. The effect of the chemical elements on the mechanical properties may be considered limited to the weld deposit and oxidation products.

Welders report that a white powderlike deposit is characteristic of 17–7PH welds, which becomes apparent when inadequate shielding is used. A sufficient sample for spectrographic analysis (Table 4) was obtained by scraping the adherent powder from the surface of a sample weld. If it is assumed that the metals in this slag are all in the oxide form because of ineffective

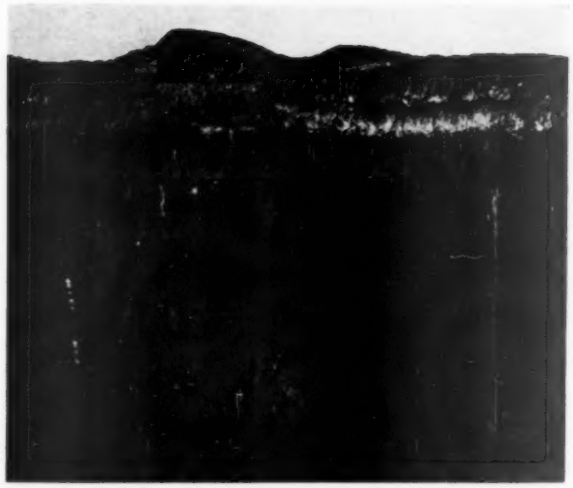

Fig. 7a Wrinkled slag surface of fusion zone of ruptured weld joint. × 2

Fig. 7b Stress raiser due to lack of fusion at interface of weld and parent metal. × 5

shielding, the composition of the deposit for the major oxides can be estimated as 22.5% alumina. This would be as anticipated in spite of the relatively low aluminum content of the alloy, because of aluminum's preferential affinity for oxygen, as exemplified by its use for deoxidation during steelmaking. The extreme refractoriness and high fusion point of this slag deposit can be observed by the granular texture of the slag as it floats on the surface of the molten metal crater. Upon solidification, this deposit forms at edges of the fusion zone in a wrinkled pattern, as shown in Fig. 7*a*, where it is particularly difficult to remove by grinding and where it introduces potential stress raisers at the interface of the fusion zone with the parent metal, as shown in Fig. 7*b*. This difficulty with a slag which contains a high amount of aluminum oxide is inherently a result of the composition of the alloy and can only be avoided by adequate shielding. It is also of interest to observe that refractory chromium oxide is more evident in the deposit than iron oxide. In considering the results

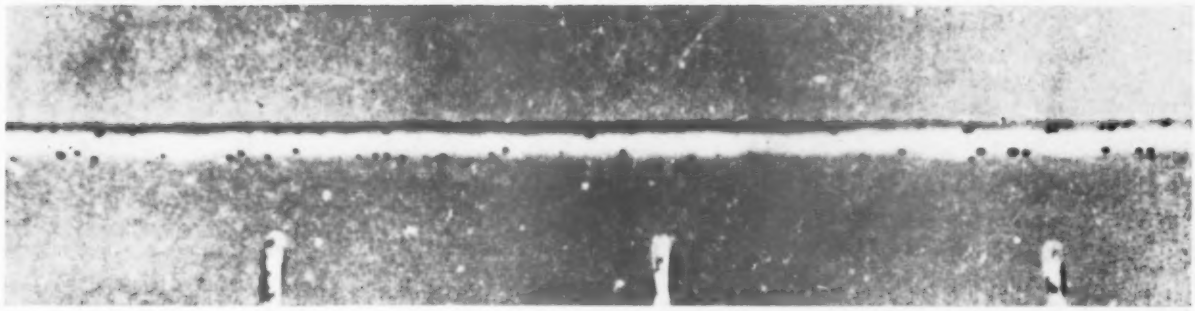

Fig. 8a Radiograph showing cavities aligned at edge of fusion zone of weld. × 2.25

listed in Table 4 for the analyses of the deposits, it should be noted that these are data for only single samples from a stringer bead deposited under argon shielding. Also, the sampling method used was not ideal, undoubtedly resulting in the inclusion of small amounts of the deposited filler metal with the particles of slag which were removed. The refractory slag produced during welding 17–7PH requires optimum conditions of shielding, and it introduces difficulties for the welder that tend to require abnormal amperage and heat input. This may damage the material by producing abnormal hardness in the heat-affected zones.

A comparison of the deposited weld metal with that of the original parent metal and filler wire has also been presented in Table 4. It was found that the analysis of the parent metal deviated to some extent from the mill analysis, as might be anticipated. The significant differences were in the aluminum and carbon content. Using volumetric adjustment for a double 45-deg beveled butt joint, the contribution from the parent metal was estimated as 40% and that of the filler wire was 60% of the total volume of the fusion zone. The aluminum loss in the joint was calculated as 10.5% and the carbon loss was 47% in spite of argon shielding at the rate of 20 cfh, which apparently was insufficient. Since the aluminum is a ferrite former and hardening agent, this loss would tend to produce a 5000-psi loss in the yield strength at 0.2% offset (Fig. 4). The large carbon loss could be even more serious because of the utility of carbon as an austenitizing agent. Attempts to use this single analysis with the Schaefler diagram have not been fruitful because of insufficient determinations to eliminate sampling and analytical errors. In addition, the diagram does not take into account the very important effect of aluminum, which is rated by Armco as twice as powerful a ferrite-former as chromium.

POROSITY IN 17–7PH WELDS

Porosity in inert-gas-shielded welds may be caused by gases introduced by the metal-shielding gas, by absorbed gases or by an unclean metal surface.[10] Examples are atomic hydrogen evolved from the metal on heating, moisture in the shielding gas, carbon monoxide from hydrocarbons, and oxygen from the metallic oxides of the surface. The form of porosity found in 17–7PH welds at Aerojet-General is unusual, in that the voids occur in a linear pattern along the edge of the fusion zone, as shown in Figs. 8*a* and 8*b*. Although linearly distributed porosity at the root of the weld is usually attributed to inadequate penetration, this effect occurs in 17–7PH with complete penetration and is absent from the centerline of the fusion zone. The localization of the porosity adjacent to the edge of the

Fig. 8b Fractured weld showing blowholes aligned at edge of fusion zone of weld. × 16

Table 5—Effect of Porosity on Mechanical Properties of Typical Welds*

Conditions	*Ult. strength, ksi*	*Yield strength at 0.2% offset, ksi*	*Elong. %/2 in.*	*Hardness,† Rockwell C*	*Porosity pores, in*
1100° F/75 min/AC, flush ground	163.6	119.6	7.0	36	0
	161.5	118.4	3.0	36	25
1025° F/75 min/AC, flush ground	186.8	140.0	4.0	42	3
	182.2	128.3	1.5	42	22
950° F/75 min/AC, flush ground	196.2	144.6	1.0	44	4
	198.5	140.0	1.0	44	14

* Weld Procedure: Simple butt joint, 0.062-in. 17–7PH filler wire. Semiautomatic argon-shielded tungsten arc, 0.031 grooved-copper backing bar.

† Heat Treating Procedure: Heat 51388 (1.04% Al) 17–7PH 0.050-in. sheet. Postweld anneal 1900° F/30 min/air cooled. Transformed 1400° F/90 min/air cooled. Aged to indicated hardness.

fusion zone suggests that the parent metal itself is responsible for the effect.

Because porosity was one of the most serious defects in 17–7PH welds, a series of studies was initiated to evaluate the significance, determine the cause, and develop a cure for the effect. A series of welds was made using 0.050-in. sheet rolled from Armco heat 51388, which was considered typical on the basis of its aluminum content of 1.04%. One-inch tensile coupons were sheared from the weldment and classified for porosity on the basis of radiographs of the weld. The coupons were selected to indicate examples of maximum and intermediate porosity in each of the series of subsequent heat-treatment conditions. Tensile test results with typical welds are summarized in Table 5. The effect of porosity on mechanical properties becomes apparent from this data. The effect of porosity on tensile strength is less than the usual errors of tensile testing. The same may be said for yield strength, with the possible exception of specimens aged at 1025° F. The most significant damage attributable to porosity was the 50% or greater loss of elongation in the heat-treated specimens, aged at 1025 or 1100° F, that possessed appreciable ductility.

A diagram such as that represented in Fig. 9 was prepared to illustrate how these results might be used to predict the elongation of a weld joint containing a given number of pores per inch, as determined radiographically. A greater number of points would obviously provide a more accurate relationship, but since the requisite degree of elongation cannot be established, the relationship of porosity to elongation is academic. The specimens aged at 1100° F exhibited the greatest degree of elongation for any given degree of porosity. The specimens aged at 1025° F appeared to have less deviation of elongation per given degree of porosity. Those specimens aged at 950° F showed a narrower deviation but no improvement of elongation with decreasing porosity.

The most obvious cause of porosity would be impurities in the gas used as a shielding atmosphere. Analyses were performed on commercial grades of argon and helium by means of a mass spectrograph, as shown in Table 6. If the trace of moisture reported for commercial argon is neglected, the results show only insignificant impurities in the shielding gases. Deliberate addition of moisture to the argon during welding produced increased porosity (about 11 pores per inch, as anticipated). Dehydration of the commercial argon, achieved by passing it through a desiccant such as calcium chloride at a rate of 17 cfh, reduced the porosity from the usual 5 pores per inch to 0.3 pore per inch. It may be concluded that even a trace of moisture in argon may contribute to the porosity of 17–7PH welds.

Substitution of helium for argon, with appropriate changes in carriage speed and current settings, reduced porosity from 5 pores per inch of weld to zero pores per inch. The ability of helium to reduce porosity may be attributed to factors other than the absence of the trace of moisture reported in the argon. The higher thermal conductivity of helium provides more heat per unit of current, which produces a large zone of preheating to precede the fusion crater. Such preheating could permit hydrogen trapped in the parent metal to diffuse to the surface and be released prior to fusion or solidification. A higher arc temperature, using helium, could produce a higher crater temperature with lower viscosity of the metal, and this would facilitate the escape of gas from the molten crater.

The mechanical properties of helium-shielded butt welds were compared by fabricating a second series of weldments, using 0.050-in. sheet rolled from Armco

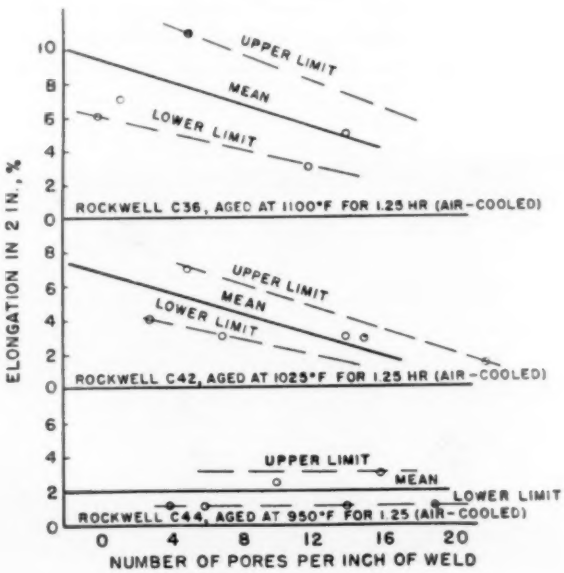
ELONGATION IN 2 IN., %
UPPER LIMIT
MEAN
LOWER LIMIT
ROCKWELL C36, AGED AT 1100°F FOR 1.25 HR (AIR-COOLED)
ROCKWELL C42, AGED AT 1025°F FOR 1.25 HR (AIR-COOLED)
ROCKWELL C44, AGED AT 950°F FOR 1.25 (AIR-COOLED)
0 4 8 12 16 20
NUMBER OF PORES PER INCH OF WELD

Fig. 9 Effect of porosity on elongation

Table 6—Mass Spectrograph Gas Analyses on Shielding Gases

	Composition, wt. %					
	A	*He*	H_2O	O_2	N_2 *or CO*	CO_2
Commercial argon	99.9+	0.0	Trace	Trace	Trace	Trace
Commercial helium	0.0	99.8	...	Trace	0.1	Trace

heat 51338. Edges were not prepared and the welds were made with filler wire, using a semiautomatic helium-shielded tungsten arc with a flat copper backing bar. One-inch tensile coupons were again sheared from the weldment and checked for porosity by examination of radiographs of the weld.

Helium-shielded welds heat treated to Rockwell C35 exhibited much greater elongation than argon-shielded welds of the same hardness because of the reduction of porosity. The ultimate stress was greater for helium than for argon-shielded welds, and the yield stress was the same for both types of welds. Increasing the hardness of helium-shielded welds to Rockwell C37 by heat treatment decreases the elongation with minor improvement of ultimate and yield stresses. Increasing the hardness to Rockwell C42 shows improved stress without loss of elongation. Comparison of helium-shielded welds with parent metal, both heat treated to Rockwell C37, shows an appreciable loss of elongation with minor yield strength improvements. It may be concluded that the best ductility is found in the welded joint prepared with a helium-shielded tungsten arc and heat treated to a hardness of Rockwell C35 (see Fig. 10).

EMBRITTLED, HEAT-AFFECTED ZONES IN 17–7PH STEEL

Weld failures in 17–7PH steel appear to start in the heat-affected zone of the weldment in most of the cases examined by the authors. Hardness traverses across the joint revealed an increased degree of hardness in the zone adjacent to fusion only in certain instances. Such abnormal hardness indicates the possibility of the existence of brittle areas incapable of yielding when stressed. Such areas would be expected to be a source for the initiation of fractures.

Because the defective parts usually fail in the heat-affected zone subsequent to forming, welding and heat treatment, it was necessary to establish the operation responsible for the abnormal hardness adjacent to the fusion zone of the weld. A weldment simulating a boss-to-tank head joint was prepared by butt welding a piece of 0.75-in. plate to a piece of 0.25-in. plate. This joint was sectioned and the hardness of the deposit, heat-affected zone, and parent metal were determined for each stage of heat treatment, as shown in Table 7. Although the hardness for each area was modified by the anneal, transformation, and aging treatments, the higher hardness of the heat-affected zone was apparent at each stage of examination. The abnormal hardness of the zone adjacent to the fusion zone apparently resulted from the heat of welding.

This weldment was also carefully examined visually for the cause of abnormal hardness in the heat-affected zone. A polished microsection of the joint revealed a slight alteration of the reflectivity of the polished surface, as shown in Fig. 11. Immediately adjacent to the fusion zone the hardness decreases about 7 points on the Rockwell B scale below that of the normal hardness level of the weld metal (see Fig. 12). This phenomenon appears reasonable in view of the extreme heat introduced by the welding arc, solidification temperatures for the metal being of the order of 2500° F and annealing occurring near 2000° F. The anomaly of increased hardness one step removed from the fusion zone also is plausible, considering the thermal gradient in

Table 7—Effect of Process Operation on Hardness of Heat-Affected Weld Zone*

Position	*Parent metal*	*Heat-affected zone*	*Fusion zone*
As-welded	B94	C22	B90
Annealed, 1900° F/15 min/AC	B90	C22	B90
Transformed, 1400° F/90 min/AC	C25	C27	C24
Aged, 1100° F/90 min/AC	C32	C32.5	C24

* Hardness is a result of an average of 6 microhardness measurements converted to Rockwell scale.

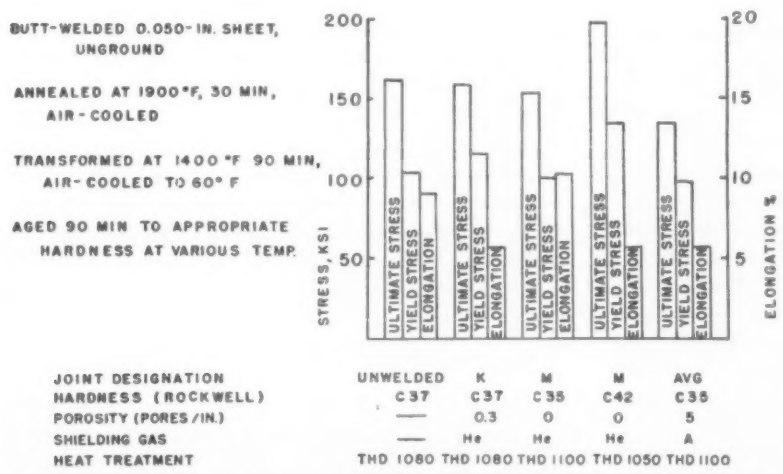

Fig. 10 Effect of shielding gas and hardness on mechanical properties of weld joint

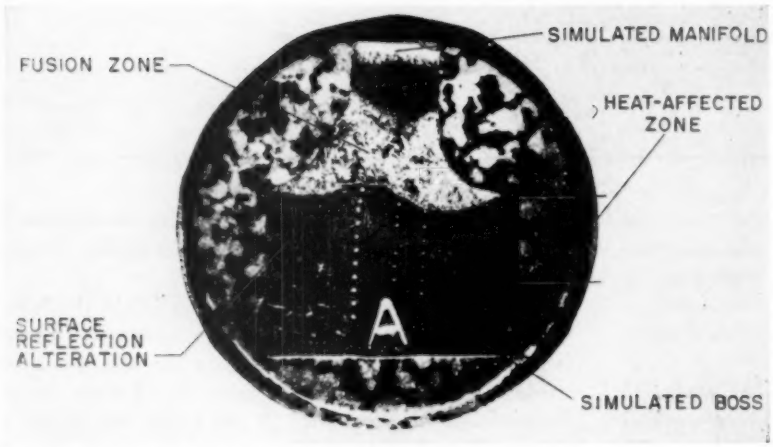

Fig. 11 Typical simulated manifold-to-boss weldment used for hardness traverses

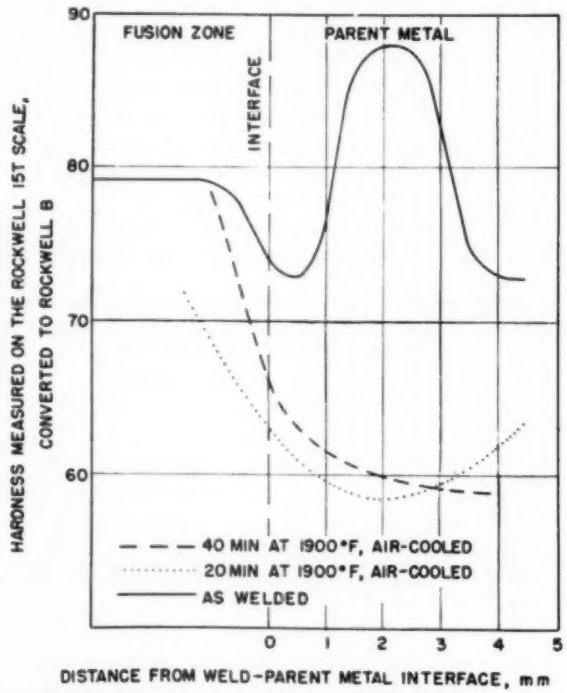

Fig. 12 Hardness variations across the heat-affected zone of the simulated manifold-to-boss weldment

the parent metal and the precipitation-hardening response of the alloy near 1000° F. Because the precipitation products are too fine to be optically resolved, the lack of modification of the microstructure is understandable. The most obvious cure for this thermal damage introduced by welding would be a solution anneal. Holding 60 min at 1900° F is Aerojet-General's practice for eliminating the abnormal hardness zones by the re-solution of the precipitation hardening agent and carbides. Although most of the effect is removed by a 20-min soak, 40 min is required for more uniform distribution and 60 min is used in practice. However, all welds do not produce this effect to the same degree, but attempts to evaluate the effect of various annealing treatments on the abnormal hardness of the heat-affected zone have been too inconsistent for comparison even on specimens from the same weld joint.

NOTCH SENSITIVITY OF 17-7PH WELDS

Aside from qualitative indications of notch sensitivity of ruptured 17-7PH weld joints, the first quantitative data were established during the porosity evaluation. The butt joints welded on 0.050-in. sheet were evaluated relative to the influence of grinding the front and back of the joint flush with the surface of the parent stock. Because conditions of fit-up were not ideal, it was necessary to reduce the specimen thickness between 15 and 20% to remove discontinuities capable of acting as stress raisers. The removal of the irregularities increased the unit stress capacity of the weld joint by 1 to 18% for the ultimate stress and 8 to 17% for the yield stress at 0.2% offset. Although the section loss on this 0.050-in. sheet was greater than the improvement in the stress capacity of the joint, improved fit-up and increased sheet thickness might indicate the advantage of flush-ground joints.

Additional tests were made to establish the significance of notch sensitivity of welds in 0.25-in. plate machined from forged stock of Armco heat 11434 containing 1.12% aluminum. Manually welded double-bevel butt joints were prepared using an argon-shielded tungsten arc. Stress raisers were introduced on the centerline and edge of the fusion zone by drilled holes. A second series of specimens of fillet welds were fabricated with machined fillets. Tensile coupons from the butt welds and bend specimens from the fillet welds were then heat treated to Rockwell C36 to C37. The introduction of mechanically produced stress raisers did not significantly alter the ultimate strength properties of the welds when corrected for the loss in section caused by the drilled holes, as shown in Table 8. The bend

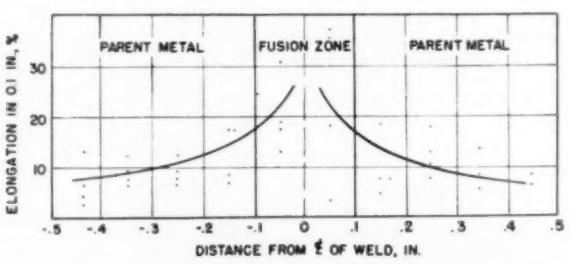

Fig. 13 Local elongation traverse across simulated manifold-to-boss weldment, illustrating low hardness of fusion zone in 17-7PH stainless steel

Table 8—Effect of Notch Sensitivity

	Tensile tests				*Bend tests*		
Joint	Butt	Butt	Butt	Butt	Fillet	Fillet	Fillet
Notch radius	None	0.375	0.250	0.125	0.125	0.050	0.025
Hardness, Rockwell C	36	36	36	36	36	36	36
Properties:							
Ultimate strength, ksi	163.6	161.1	165.0	163.8	1580 (lb)	1275 (lb)	1300 (lb)
Yield stress, ksi	119.7	148.5	143.1	137.1	...	...	...
Elong, %/2 in.	7.5	2.5	2.0	2.0	...	...	...
Angle of rupture, deg	...	...	...	...	23	13	19.5

specimens also exhibited good ductility and they finally fractured in the heat-affected zone. Although the comparison of the 0.25-in. plate with the 0.050-in. sheet is not as fair as would be desired, results tend to indicate that small discontinuities attributable to slag or nonfusion are more significant than are mechanically introduced discontinuities.

Since the ductility of the welds was so much in question, the elongation over 0.1-in. gage length increments across a pulled weld tensile specimen was measured. In spite of the crudeness of the test, the elongation of the weld deposit approached at least 22%, as contrasted with 5 to 8% for the parent metal as shown in Fig. 13. From this it would appear that at least the weld deposit was not the cause of the over-all lack of ductility in the welded joint.

CONCLUSIONS

1. Heat-treatment response of the mechanical properties of 17–7PH steel is seriously affected by the chemical composition of the heat. The austenitic balance and initial transformation temperature are especially sensitive to the carbon and aluminum contents.

2. Precipitation-hardening at Aerojet-General is conducted at 1100° F to obtain maximum ductility and utilize the more gradual mechanism of overaging to improve control of the mechanical properties of strength and ductility. The property of ductility should be evaluated more closely to establish requirements in bend, tension or impact.

3. The aluminum content of 17–7PH tends to oxidize preferentially to form a white slag if the metal is insufficiently covered with inert gas in the inert-gas-shielded tungsten-arc-welding process. The carbon and aluminum contents of the deposited metal are subject to losses during welding in sufficient quantities to affect the heat-treatment response and mechanical properties of the deposited metal. Determinations of element losses in the arc for various conditions of welding should indicate methods of control if the losses cannot be prevented.

4. The form of porosity in automatically prepared 17–7PH welds is distinctive because of the occurrence of voids in a linear pattern along the edge of the fusion zone. This suggests that gas liberated from the parent metal may be responsible for this type of porosity. Such porosity is capable of serious damage, resulting in approximately 50% loss of elongation. Superior elongation per given degree of porosity can be obtained by use of a higher aging temperature such as 1100° F. The influence of the degree of porosity is less for a lower aging temperature, such as 950° F, because the ductility of the parent metal is decreased. This illustrates the significance of ductility in overcoming the rupture-causing tendencies of discontinuities such as porosity.

5. Moisture in argon-shielding gas can cause porosity in 17–7PH automatically prepared welds, and even a trace amount may be significant. Substitution of helium for argon in automatically prepared welds practically eliminated porosity by a mechanism possibly resulting from higher arc temperatures. Porosity may result from accelerated welding speed or rapid solidification rates of the crater.

6. Helium-shielded tungsten-arc automatic welds exhibit almost double the elongation with equivalent or superior strength at the same hardness level, Rockwell C35, in comparison with argon-shielded welds. This is believed to result from a reduced porosity in the helium welds. Helium-shielded welds show a 50% loss of elongation by increasing the hardness level from Rockwell C35 to C37. Helium-shielded welds compared to unwelded metal at a hardness of Rockwell C37 show 40% less elongation.

7. Abnormal hardness in the heat-affected zones of 17–7PH welds was found at each stage of heat treatment, and the effect is believed to be a result of heat input during welding. Although the effect was not apparent in the microstructure, a variation in the degree of reflectivity of the microsurface was apparent. Hardness traverses show a soft and a hard zone, believed to be related to the thermal gradient during welding. The abnormality is eliminated by a 40-min anneal at 1900° F.

8. Notch sensitivity of 0.050-in. sheet welds was indicated by a 17% improvement of the yield stress load of the joint upon grinding the surfaces of the weld joint flush. Additional weld joints on 0.25-in. plate exhibited no strength loss attributable to drilled holes in the weld area. Bend tests on small fillets also indicated excellent ductility.

ACKNOWLEDGMENTS

The authors desire to express their appreciation for the contributions of E. W. Brady, L. L. Gilbert, F. A. Stevenson, G. A. Gardner and other members of the Aerojet-General organization without whose help this

paper could not have been prepared. Particular credit is due to H. Kimball and K. Leovich, who prepared the micrographs and did much of the test work.

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Effects of Prestressing on Fatigue Strength of Spot-Welded Stainless Steels

Prestressing by hydrostatic means, compression, tension and peening can be used to increase the fatigue strength of spot-welded joints

by Andre Choquet, V. N. Krivobok and Georges Welter

Abstract

Engineers in various fields have expressed interest in the fatigue properties of austenitic stainless steel joined by the spot-welding method. Fatigue strength of various metals and alloys are often judged by their ratio to tensile strength or shear strength; however, it was evident that this tensile strength-fatigue strength ratio cannot be applied to stainless steel spot-welded joints. Fatigue tests performed on 1, 2, 3 and other multiple-spot-welded sheet specimens produced data on the effect of such variables as spot pattern, interspot distances, etc. In addition, and more important, experimental data were found on the important improvement obtainable in fatigue characteristics if prestraining is performed on the spot weld. This increase is evident whether the straining is accomplished by "hydrostatic" compression, simple compression, tension or hand peening. Hydrostatic compression produces the greatest improvement, with a gradual increase in fatigue strength taking place as the hydrostatic compression load is increased to 400,000 psi. Progressive loading or "training" of specimens after hydrostatic compression, proves that a large number of cycles at lower loads will not alter the beneficial effect of prestressing. In addition to prestressing, by hydrostatic means, simple compression, tension and hand-peening methods may be employed to obtain significant increases in fatigue characteristics of these spot-welded joints. The mechanism (emphasis on origin, location and path) of fatigue failure in spot-welded samples is ascertained as well as the probable limits of a ratio between fatigue strength of parent metal and that of a spot-welded joint.

1. FOREWORD

SINCE spot welding offers so many advantages as a method of joining structural components made of stainless steel, the International Nickel Co., Inc., has sponsored an investigation, the purpose of which was to develop basic data on the strength of these components when joined by spot welding methods.

Andre Choquet, École Polytechnique, Montreal, Canada; **V. N. Krivobok** International Nickel Co., New York, and **Georges Welter**, École Technique, Montreal, Canada.

Scheduled for presentation at the Thirty-Fifth AWS National Fall Meeting to be held in Chicago, Ill., the week of Nov. 1–5, 1954.

The interest in fatigue properties of spot-welded joints has often been expressed by engineers from various fields. More specifically the aircraft engineers have visualized instances where spot-welded joints would be subject to cyclic or fatigue stresses. A literature search on the subject revealed little if any test data; however, practical experience of considerable duration, as for example in railway car construction, assured the engineers of the adequacy of strength in spot-welded joints. Practical experience with the above mentioned example of railway cars did not necessarily include conditions of true fatigue and therefore, this specific information was still needed.

A testing program subsequently carried out revealed startling preliminary results. The fatigue strength of various wrought metals and alloys is often judged by the ratio to their tensile strength (usually between 45 and 50%). In the case of spot-welded joints their fatigue strength was compared with shear strength (on a per spot basis) and when such a comparison was made, unexpectedly low figures for fatigue strength:shear strength ratio have been secured. This is evident from Figs. 1 and 2. Similar results were obtained in two independent research laboratories.

Test samples, on which above described observations were made, contained multiple spots: from 5 to 52 spots per sample.

Further work was undertaken and only recently completed. It was carried out on samples which had only 1, 2 or 3 spot welds, since with smaller number of spots the distribution of test stress would be less complex. This is an important consideration since, in the author's opinion, the explanation of the unjustifiably and unexpectedly low test figures on multiple spot samples could be the result of uneven division of stress among spot welds and resulting complex stress pattern in the sample.

Thus, the objective of the investigation described herein was as follows:

(*a*) To determine the fatigue strength of single spot (under controlled conditions as to size, welding technique, etc.), *without* added complexity of stress division

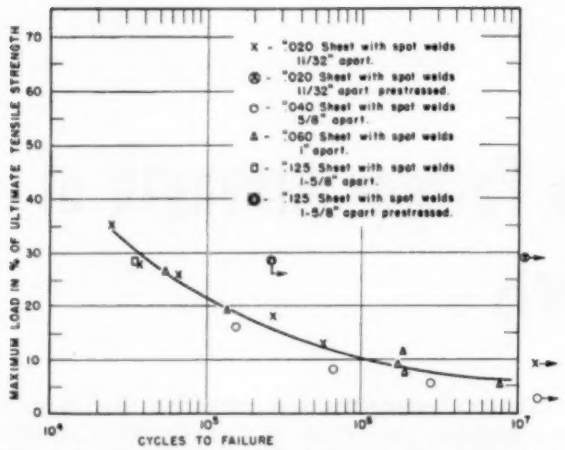
MAXIMUM LOAD IN % OF ULTIMATE TENSILE STRENGTH
CYCLES TO FAILURE
X - .020 Sheet with spot welds 11/32" apart.
⊗ - .020 Sheet with spot welds 11/32" apart prestressed.
○ - .040 Sheet with spot welds 5/8" apart.
△ - .060 Sheet with spot welds 1" apart.
□ - .125 Sheet with spot welds 1-5/8" apart.
● - .125 Sheet with spot welds 1-5/8" apart prestressed.

Fig. 1 Fatigue strengths of double-row spot-welded stainless steel lap-joint specimens. Results of the investigation conducted at Battelle Memorial Institute and sponsored by International Nickel Co., Inc.

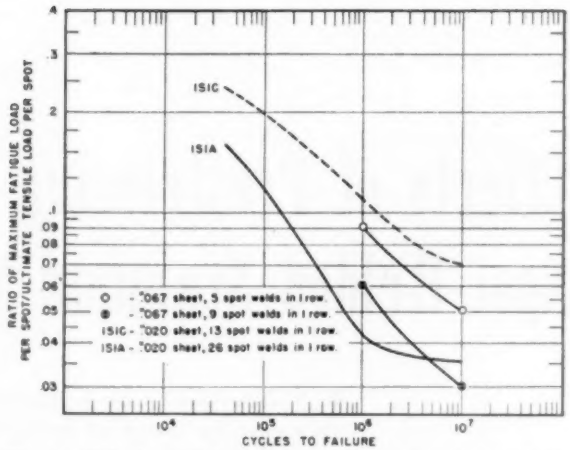
RATIO OF MAXIMUM FATIGUE LOAD PER SPOT/ULTIMATE TENSILE LOAD PER SPOT
CYCLES TO FAILURE
ISIC
ISIA
○ - .067 sheet, 5 spot welds in 1 row.
● - .067 sheet, 9 spot welds in 1 row.
ISIC - .020 sheet, 13 spot welds in 1 row.
ISIA - .020 sheet, 26 spot welds in 1 row.

Fig. 2 Relation of fatigue strength per spot to static strength per spot for spot-welded joints in 0.020-in. stainless steel sheet. Results of the investigation conducted at Battelle Memorial Institute and sponsored by International Nickel Co., Inc.

and, thus, provide a basis for comparison of multiple spots.

(*b*) To obtain data on the probable limits of a ratio between fatigue strength of parent metal and that of a spot-welded joint.

(*c*) To ascertain the extent to which the fatigue strength of a joint is lowered by additional spot welds.

(*d*) To observe the influence of such variables as spots pattern, interspot distances, etc., on austenitic stainless steel spot-welded joints.

(*e*) To ascertain the mechanism (emphasis on origin, location and path) of fatigue failure in spot-welded samples.

(*f*) To provide factual data on the improvement in the fatigue life of a joint through "hydrostatic compression" application.

2. DESCRIPTION OF SPECIMENS

The material used was AISI Type 301 stainless steel sheet, half hard temper, of the following composition and strength:

Carbon	0.11
Manganese	0.73
Phosphorus	Low
Sulfur	Low
Silicon	0.63
Nickel	6.70
Chromium	17.80
Tensile strength, psi	168,000
Yield strength (0.2% offset), psi	128,500
Fatigue strength, psi	100,000

In addition to fatigue tests of plain stainless steel sheet (17-7), one single, two horizontal and three "triangular shape" spot-welded sheet specimens were tested in the 0.024 and 0.067 in. thickness (Fig. 3). The distance between spots and rows was kept constant at $^5/_8$ in., center to center for both thicknesses of material.

The spot dimensions were "standard" as recommended by the usual spot welding technique* and were $^1/_4$ in. diam for the 0.067 in. sheet and $^1/_8$ in. diam for the 0.024-in. sheet. All test specimens were 1.5 in. wide and 11.5 in. in length. Overlap was set at $^7/_8$ in. for the one- and two-spot specimens and at 1.5 in. for the three-spot specimens.

* As developed by the Budd Co.

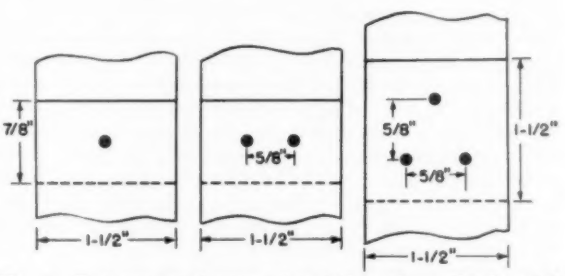

Fig. 3 Fatigue specimens of stainless sheet (17-7) with one single-, two horizontal- and three triangular-shaped spot welds which were tested in the 0.024 and 0.067 in. thickness

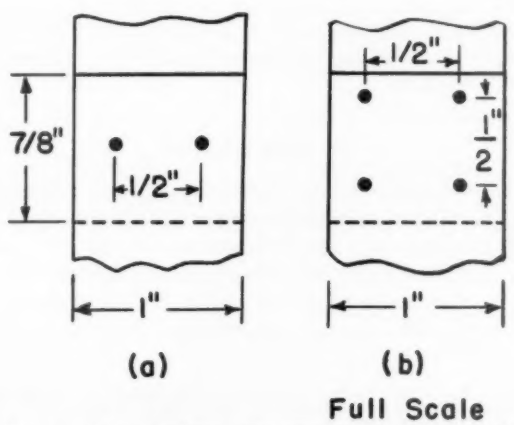

Fig. 4 A few fatigue specimens were tested with patterns and size as shown in (a) and (b)

A few samples of the pattern and size shown in Fig. 4 were also tested.

3. DESCRIPTION OF TEST EQUIPMENT (KROUSE TESTING MACHINE)

Fatigue testing was done on a Krouse Direct Repeated Stress Double Testing machine with a 5000 lb capacity and a speed of 1500 rpm. The principle of this machine is well known and need not be described here. All specimens were tested under a constant ratio of minimum to maximum load of $R = 0.20$. Two specimens were tested at a time and as soon as fracture occurred, the machine would automatically stop. The loading grips were equipped with universal joints for true axial alignment since the specimen works only in tension. Further improvement in the design of the joints consists of the incorporation of several hundred steel balls, $^1/_{16}$ in. diam, on which rests the concave and convex surfaces of the joints. The testing machine is shown in Fig. 5.

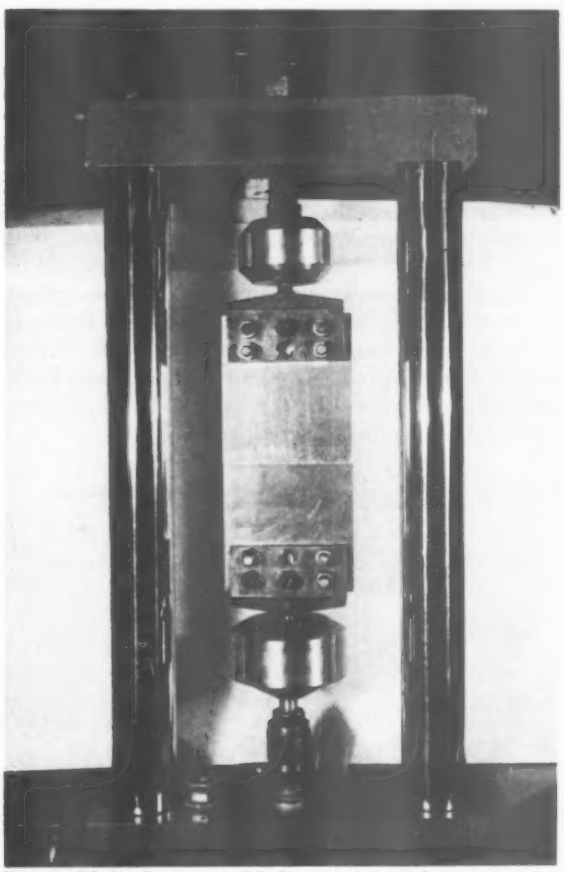

Fig. 5 Multiple-spot-welded specimen in fatigue testing machine

4. DESCRIPTION OF TESTING PROCEDURE

(a) *Fatigue Testing*

The evaluation of fatigue strength of the test specimens was done in accordance with standard procedure i.e., with individual specimens tested to failure to obtain experimental values, represented by points on the S–N curve. The fatigue load was taken to be that load which after ten million cycles produced no failure. The use of "fatigue" load rather than customary "fatigue" strength (in psi) is deliberate for the reasons described later on.

A record of the lever variations was made twice a day and no resetting was done until fracture occurred or ten million cycles were reached.

(b) *"Hydrostatic" Compression*

The "hydrostatic" compression technique was employed to improve the fatigue characteristics of the spot-welded joints. This method consists of applying a localized high pressure on the $^1/_4$ in. diam or $^1/_8$-in. spot while preventing any lateral flow of the material. This was performed by solidly clamping the joint containing the spot weld or welds between two steel dies and inserting the assembly in a Universal testing machine. Pressure is brought to bear on the spots by two cylindrical tips, one on each side of the nugget. The operation was as follows: (1) Clamp the joint in the appropriate die (depending upon spots and sheet thickness). (2) Apply compression on the spot via the tip by the Universal machine. No fluid or packing of any kind was used in this process.

Through previous experience on other materials, a 400,000 psi pressure was found desirable to produce significant results.

Preliminary investigation revealed a $^1/_4$-in. hardened drill rod steel tip, prestressed in compression and ground to the size of the dies could resist a compression load of 20,000 lb, the equivalent of 400,000 psi, without deformation or failure in the dies. These tips had to be replaced periodically after a certain number of compressions.

Two sets of dies were made to accommodate the 2-spot diameter using the two-sheet thicknesses. Dies for the $^1/_4$-in. diam spots were later machined to allow $^5/_{16}$-in. tips to be used and thereby allow the compression of both the spot and the heat-affected zone. The hydrostatic compression device is shown in all its simplicity in Fig. 6.

Fig. 6 Hydrostatic compression device in all its simplicity

Table 1—Fatigue Testing on Plain Stainless Steel Sheet (17–7) of 0.067 In. Thickness and 0.375 In. Width

Area: 0.0245 in.²

Spec. No.	*Max. stress, psi*	*Actual load applied, lb*	*Cycles to failure*	*Fatigue ratio*	*Remarks*
32	142,000	3500	23,000	0.84	Cracked in center
14	114,000	2800	159,900	0.68	Cracked in center
14A	102,000	2500	3,780,000	0.60	Cracked in center
32A	102,000	2500	1,513,700	0.60	Cracked in grips
33	98,000	2400	1,625,900	0.58	Cracked in grips
33A	98,000	2400	11,311,700	0.58	Did not fail
33B	90,000	2200	12,937,600	0.54	Did not fail

Static testing results:
Maximum tensile strength, psi 168,500
Yield strength, psi 128,500

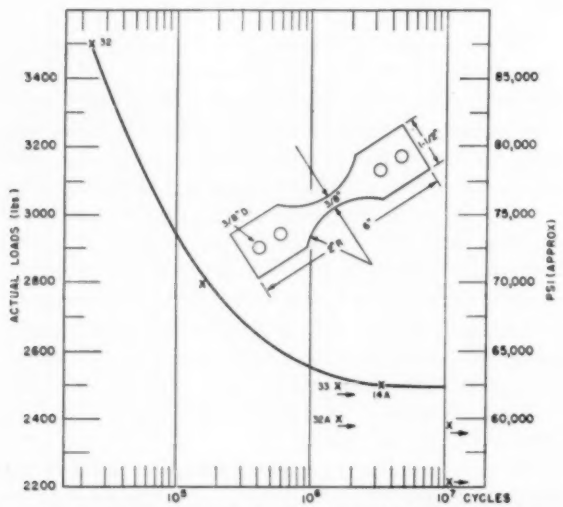

Fig. 7 Fatigue properties for 0.067-in. thick plain stainless steel 17–7 half hard temper sheet similar to spot-welded samples

5. RESULTS

(a) *Fatigue Testing on Plain Stainless Steel 17–7 Sheet*

In order to evaluate the sheet material used for spot-welded joints, specimens were machined from samples with the spot welds drilled out. Each spot-welded specimen would yield two stainless steel specimens no longer than 6 in. which were later machined to a 4-in. long reduced section, leaving $1^1/_2$-in. length for gripping.

Results for the fatigue testing of these stainless steel sheets of 0.067 in. thickness and 0.375 in. width are presented in Table 1 and shown graphically in Fig. 7.

One similar fatigue specimen was tested statically to determine a fatigue ratio. This ratio is equivalent to the fatigue load divided by the load corresponding to the maximum tensile strength of the material, both values taken from a similar section.

Owing to the short length of the specimen, difficulties were encountered with fatigue specimen failing in the grips rather than in the reduced section. Nevertheless, enough specimens were tested to give a representative *S–N* curve (Fig. 7) for the 17–7 stainless steel half hard temper under investigation.

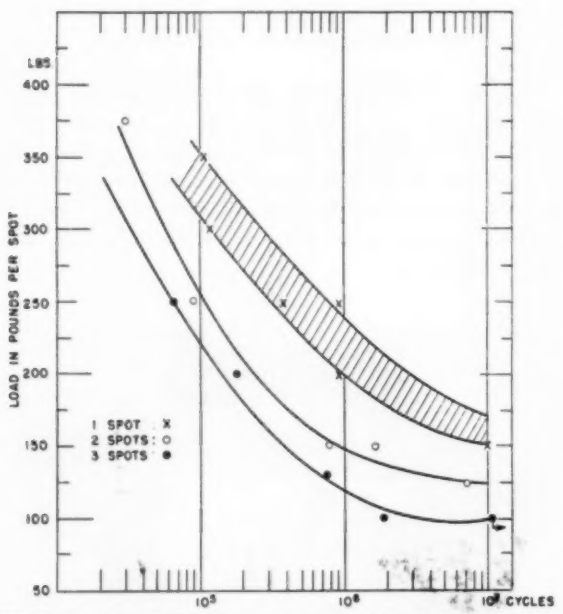

Fig. 8 Fatigue properties on a per spot basis for 1, 2, and 3 spot as-received specimens in 0.024-in. stainless steel spot-welded sheet

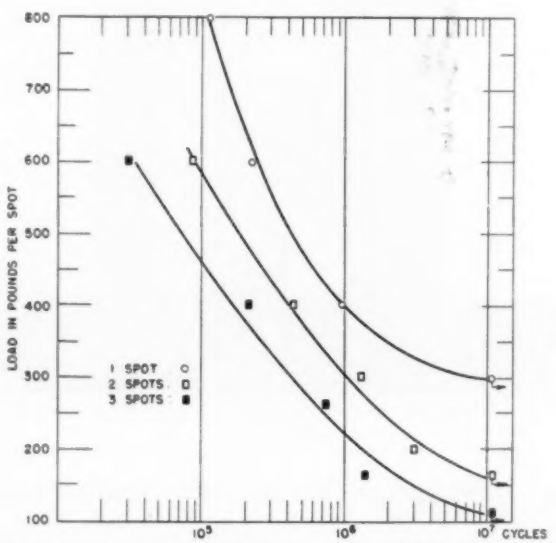

Fig. 9 Fatigue properties on a per spot basis for 1, 2 and 3 spot as-received specimens in 0.067-in. stainless steel spot-welded sheet

(b) *Fatigue Testing of Samples as "Spot Welded" (Not Hydrostatically Treated)*

Complete *S–N* fatigue curves were determined for 1-, 2- and 3-spot-welded joints having a $1^1/_2$ in. width and for both 0.024 and 0.067 in. thicknesses. Figures 8 and 9 show the general relationship of a number of cycles to failure and load in pounds per unit spot for 0.024- and 0.067-in. thick joints, respectively.

Accepting 10 million cycles as a generally adopted basis for fatigue studies, the loads per spot to cause fatigue failures are as follows:

	0.024 in. thick	*0.067 in. thick*
1 spot	150 lb	300 lb
2 spots	125 lb	160 lb
3 spots	100 lb	115 lb

The following observation is evident from this data: as the number of spots per sample is increased, the load (per spot) to cause localized failure is decreased.

Previous work on samples with multiple (8) spots, see Fig. 10, did not allow the evaluation of the possible effect of the spots pattern. In an effort to study this

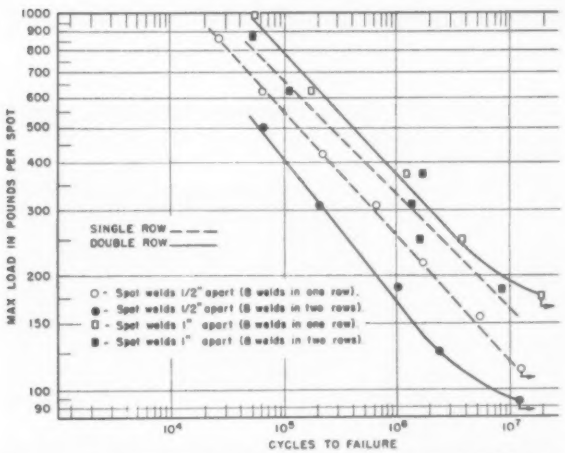
MAX LOAD IN POUNDS PER SPOT
CYCLES TO FAILURE
SINGLE ROW
DOUBLE ROW
O - Spot welds 1/2" apart (8 welds in one row).
● - Spot welds 1/2" apart (8 welds in two rows).
□ - Spot welds 1" apart (8 welds in one row).
■ - Spot welds 1" apart (8 welds in two rows).

Fig. 10 Fatigue properties, per spot, of spot-welded joints in 0.060-in. stainless steel sheet. Results of the investigation conducted at Battelle Memorial Institute and sponsored by International Nickel Co., Inc.

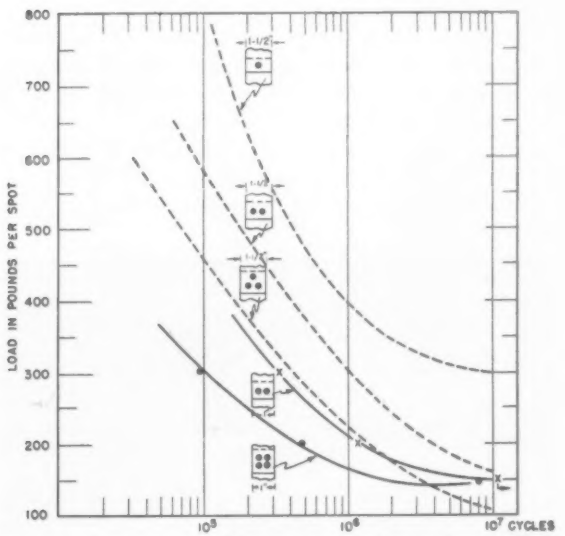

Fig. 11 Comparison of fatigue properties in a pound per spot basis with variations in number of spots, specimen width, distance between spots and rows for 0.067-in. untreated spot-welded stainless steel joints

Dash curves are reproduced from Fig. 9 where distance between spots and rows is $^1/_2$ in. Full line curves stand for 1-in. wide specimen with a distance between spots and rows of $^1/_2$ in. (center to center).

Fig. 12 As-received 3-spot specimen after fatigue failure

Fig. 13 Close-up view of one of the spots shown in Fig. 12

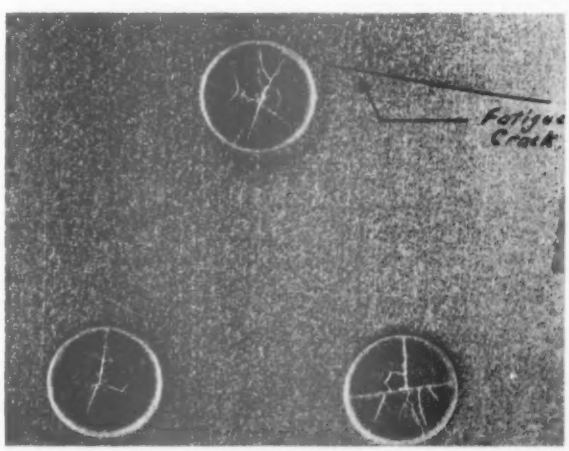

Fig. 14 Fatigue failure of specimens similar to that shown in Figs. 12 and 13, but this specimen has been hydrostatically treated

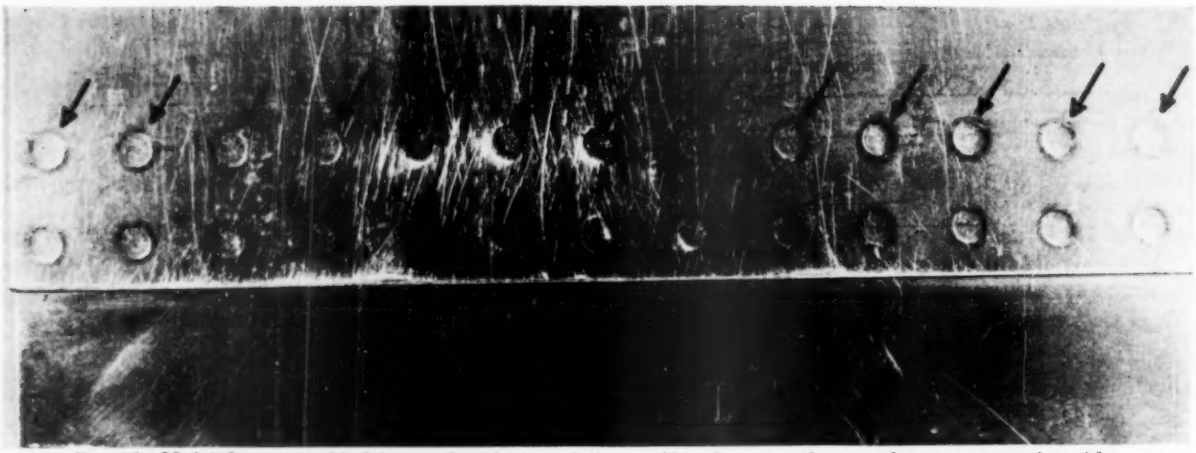

Fig. 15 Multiple-spot-welded joint after fatigue failure. Note fracture above each spot, on tension side

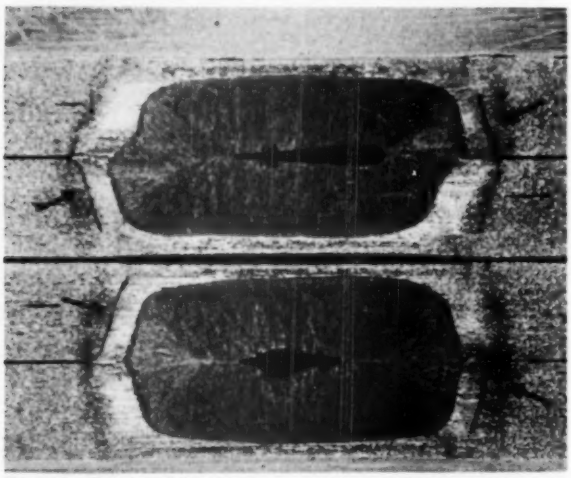

Fig. 16 Origin of fracture on a 0.067-in. thick specimen at the ends of the heat-affected zone

Fig. 17 Photomicrograph of fatigue failure near spot weld in untreated spot-welded joints. Sheet thickness is 0.020 in. Etchant CrO_3HCl. Magnification, × 50

variable, a few tests were run on samples with one to four spots with the results shown in Fig. 11. (Additional tests with as many as 52 spots gave results shown in Figs. 33 and 34.) Previous indication of the importance of the spacing between spots was hereby confirmed; however, the only evident conclusion is that the fatigue strength per spot falls off as the number of spots is increased.

So far, the comparison of the strength of joints in fatigue has been made against the strength in tension (shear). Such a comparison can be made directly if it is postulated that the failure, whether in tension or in fatigue, takes place *through the spot*. As will be described shortly, such an assumption is not correct.

(c) *Examination of Failed Samples and Location of Fatigue Cracks*

Minute examination of numerous samples that were made to fail by fatigue, disclosed that *all* of the samples failed through cracking. The location of the crack was never in the weld nugget (spot weld area itself) but always very close to the spot as shown in Figs. 12, 13 and 14. This was true whether the test piece contained 1, 3 or as many as 26 spot welds (Fig. 15).

Careful metallographic investigation of sectioned samples that had failed proved more specifically that the fatigue crack takes place in the heat-affected zone of the parent (sheet) metal (Figs. 16 and 17). Furthermore, the fatigue crack initiates at the under side or at the interface of the (spot-welded) joint, on the tension side and progresses toward the outside surface of either

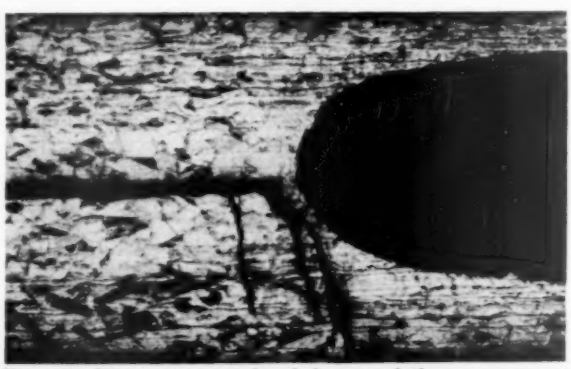

Fig. 18 Photomicrograph of fatigue failure near spot weld in untreated spot-weld joint. Sheet thickness is 0.020 in. Marble's etch. × 50

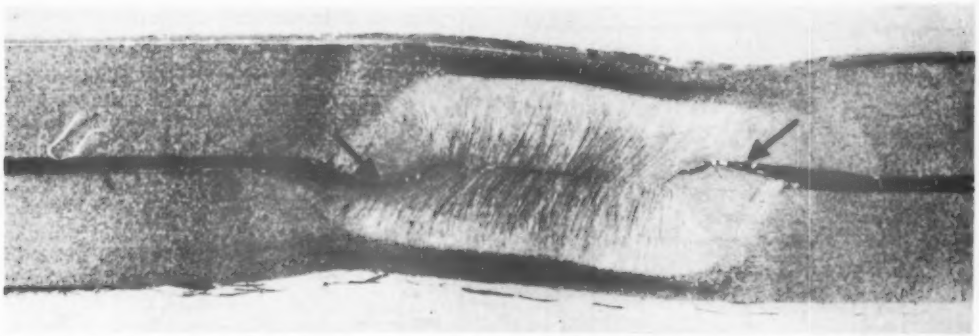

Fig. 19 Initiation of a shear fracture in a static tension test on a 1-spot, 0.067-in. thick stainless steel spot-welded specimen

sheet. This is well illustrated in Figs. 15 and 18. This location of failure (Fig. 18) is the one in which the stress concentration is relatively high because of the notch line character of the two sheets joining the weld nugget.

These observations are in full accord with previous experience, i.e., the use of guiding sheaths or some similar device to minimize bending (as a result of nonconcentric loading) is of primary importance if reliable data are to be obtained.

In a static tension test the predominant mode of failure is truly that of a shear nature (the reason for calling this type of test "tension" or "shear") as is shown in Fig. 19 (for 0.067-in. specimens). In spot-welded sheets of thin gages (for example, 24 gage), the failure in the tension test took another form: the whole welded nugget was torn out of the sheet. Any comparison, therefore, of tensile (shear) and fatigue strength is not warranted and the values of ratio, etc., are meaningless, since in one case we obtain experimental values for cast metal—weld nugget, while in the other we test the resistance of heat-affected, i.e., annealed (or partially annealed) sheet material to failure through fatigue. Please note there is no way to measure the cross section of the "annealed" material and, therefore, the calculation of the stress at failure cannot be given in pounds per square inch. Rough calculations, including admittedly questionable assumptions, intimate that, at least in case of single spots, the fatigue strength of a joint is close to the known values of fatigue strength for annealed stainless.

For the above reasons, it seemed proper to evaluate the fatigue strength of the joints in terms of "total load" or "load per spot" and investigate the means by which the strength could be improved. Approximate static *rupture load* or pull test (shear) strength for 1, 2 and 3 spot samples on a per spot basis* gives the following approximate results:

0.024 in. thick	900 lb
0.067 in. thick	4000 lb

* See Fig. 27. Similar values were reported by the Budd Co., who kindly supplied the welded specimens.

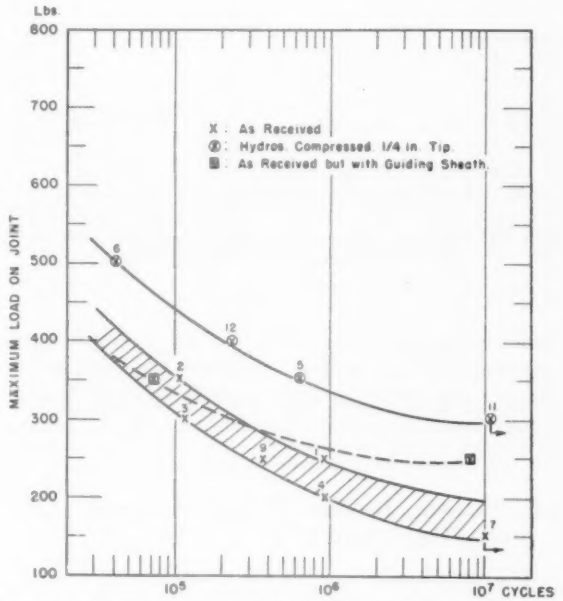

Fig. 20 Fatigue curves for 1-spot, 0.024-in. thickness, stainless steel spot-welded specimens

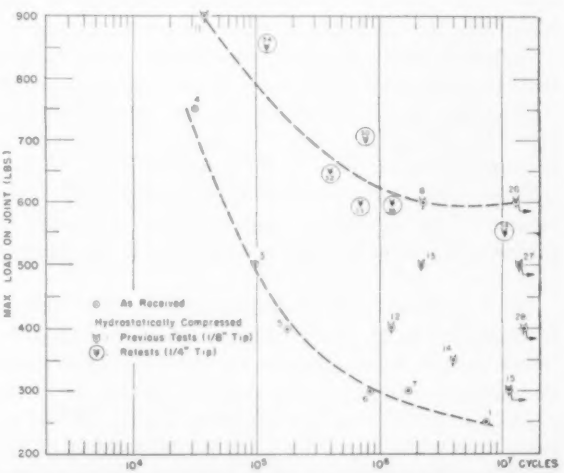

Fig. 21 Fatigue curves for 2-spot, 0.024 in. thickness, stainless steel (17-7) spot-welded specimens

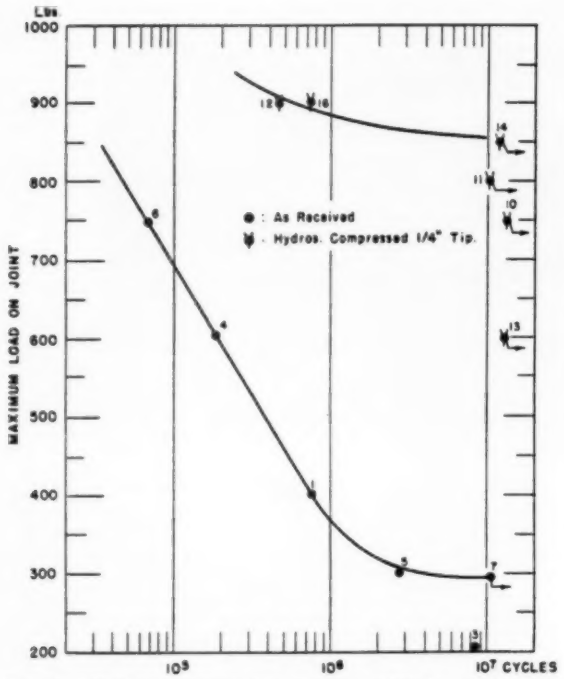

Fig. 22 Fatigue curves for 3-spot, 0.024-in. thickness, stainless steel spot-welded specimens

Again it has been confirmed that the strength of the spot-welded joints tested in fatigue when compared to the strength of similar joints tested in straight tension, is very low.

(d) *Fatigue Testing of Hydrostatically Compressed Specimens*

The hydrostatic compression treatment as described previously was applied to both thicknesses of material in each of the three spot patterns. Tips of $^1/_4$ in. diam were used under a load of 20,000 lb to exert a pressure of 400,000 psi on the 0.067-in. thick samples. For an equivalent pressure, a 5000-lb load was used on the $^1/_8$-in. tips for the 0.024-in. thick spot-welded samples.

Following this treatment the samples were fatigue tested on the Krouse machine in the regular manner. The results for the 0.024-in. material are recorded in Figs. 20 through 22. For the purpose of comparison, previously secured data on the samples as-received, i.e., without hydrostatic treatment, is included in these figures. The degree of improvement achieved in fatigue characteristics through hydrostatic prestressing is evident.

Hydrostatically compressed specimens 12, 13 and 14 as shown in Fig. 21, produced three defective test results. These results were obtained by applying hydrostatic compression using a $^1/_8$-in. tip instead of the usual $^1/_4$-in. tip to the very thin stainless sheets. When retests were made using the $^1/_4$-in. tip (specimens 30, 32, 33, 34 and 35), results conformed to the fatigue curve that had already been established.

Similar data on 0.067-in. material is shown in Figs. 23 through 25. Here again the beneficial effect of the hydrostatic treatment is clearly brought out.

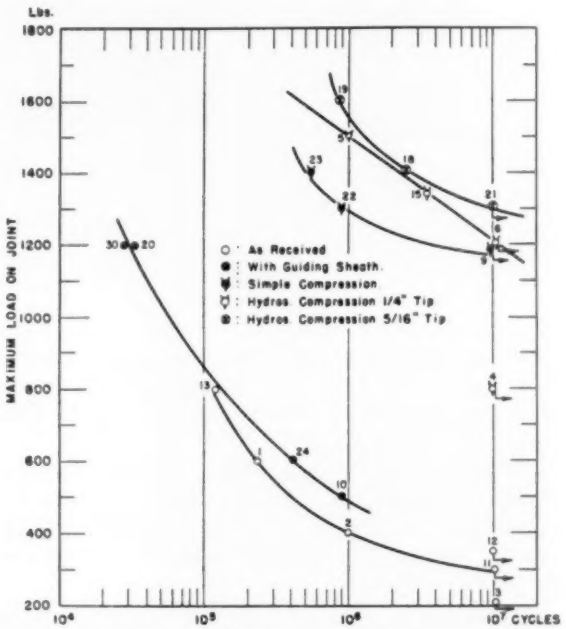

Fig. 23 Comparison of fatigue curves for 1-spot, 0.067-in. thickness, stainless steel spot-welded specimens

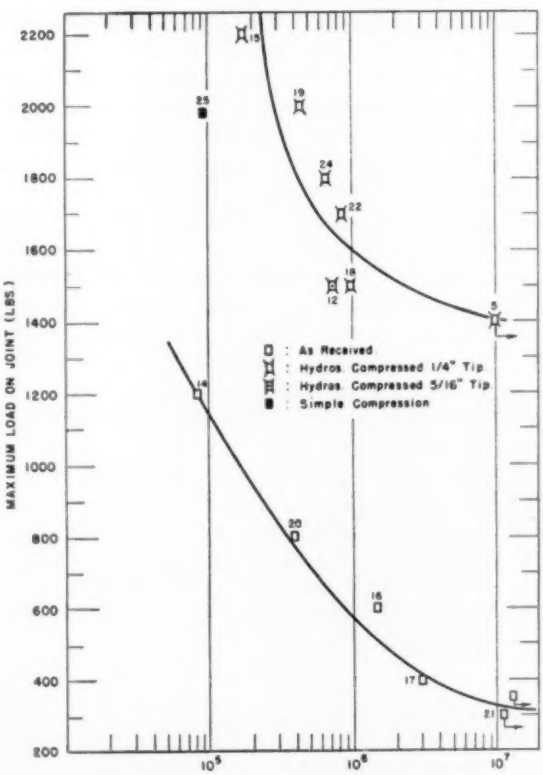

Fig. 24 Fatigue properties for 2-spot, 0.067-in. thick, treated and untreated specimens

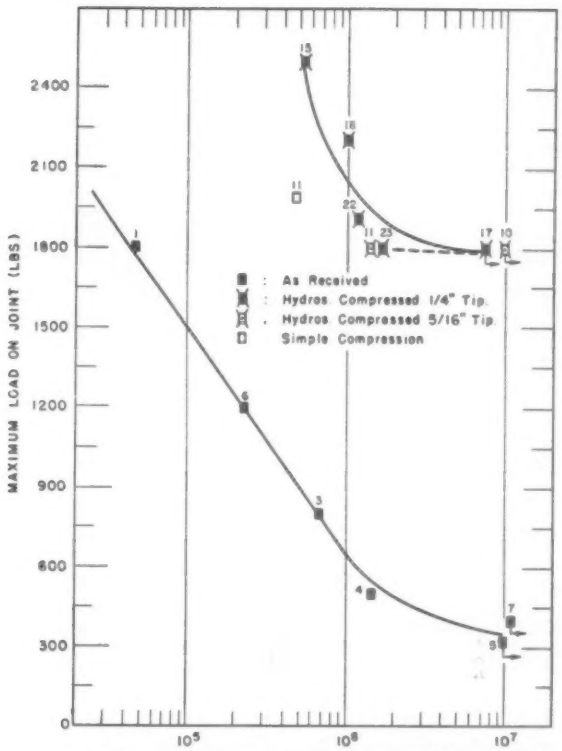

Fig. 25 Fatigue properties for 3-spot, 0.067-in. thick, treated and untreated specimens

Table 2 gives a summary of the improvement in fatigue strength that can be obtained by hydrostatic treatment based on tests of ten million cycles' duration.

Additional tests invariably upheld the observed beneficial effects of hydrostatic treatment. A sample (0.067 in.) with 3 spots in one row failed under a load of 1200 lb after about 7 million cycles. The same sample hydrostatically treated went over 10 million cycles under the load of 4500 lb and would not fail.

A sample with 5 spot welds "as-received" failed after 60,000 cycles under the load of 4000 lb. After hydrostatic treatment, the record of the similar sample was 486,000 and 817,000 cycles under the same load.

The limited capacity of testing machines did not permit testing of multiple spots, pretreated samples, to failure and thus establish a complete *S–N* curve; however, every test, even though not carried to failure, upheld previous observations on the benefits of hydrostatic prestressing.

Figures 26 through 29, composed for 1-, 2- and 3-spot welds in 0.024- and 0.067-in. thickness material suggest the *S–N* curves on the "load per spot vs. cycles to failure" basis.

Table 2—Load Carried in Fatigue with No Failure in 10^7 Cycles

	Load on joint, lb		*Load per spot, lb*	
	0.024 in.	*0.067 in.*	*0.024 in.*	*0.067 in.*
1 spot				
Untreated	150	300	150	300
Treated	300	1200	300	1200
Improvement by treatment, %	100	300	100	300
2 spots				
Untreated	250	320	125	160
Treated	600	1400	300	700
Improvement by treatment, %	140	337	140	337
3 spots				
Untreated	300	345	100	115
Treated	850	1800	285	600
Improvement by treatment, %	185	420	185	420

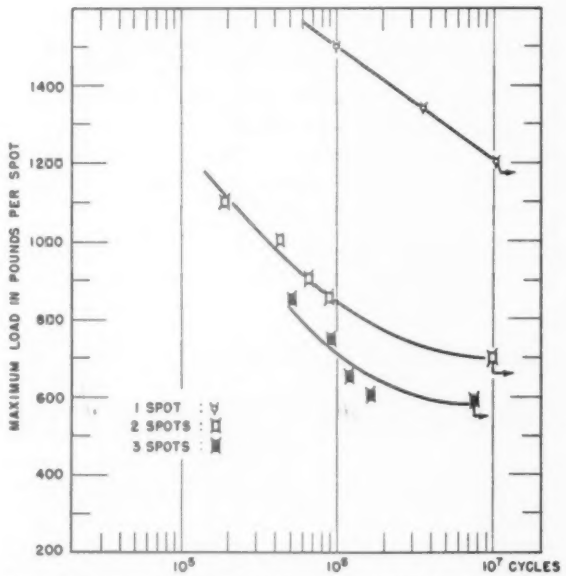

Fig. 26 Comparison of fatigue properties in pound per spot values for hydrostatically treated 1-, 2- and 3-spot specimens in 0.067-in. stainless steel spot-welded sheet ($^1/_4$-in. tip and 400,000 psi compression)

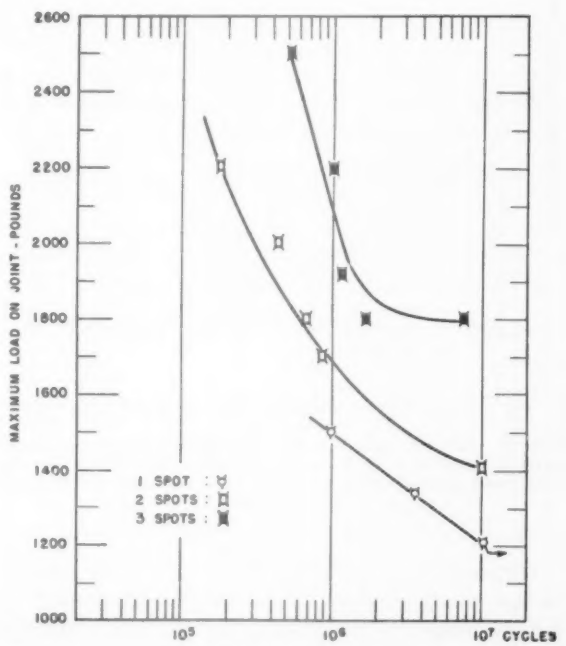

Fig. 27 Comparison of fatigue properties for hydrostatically treated 1-, 2- and 3-spot specimens in 0.067-in. stainless steel spot-welded sheet ($^1/_4$-in. tip and 400,000 psi compression)

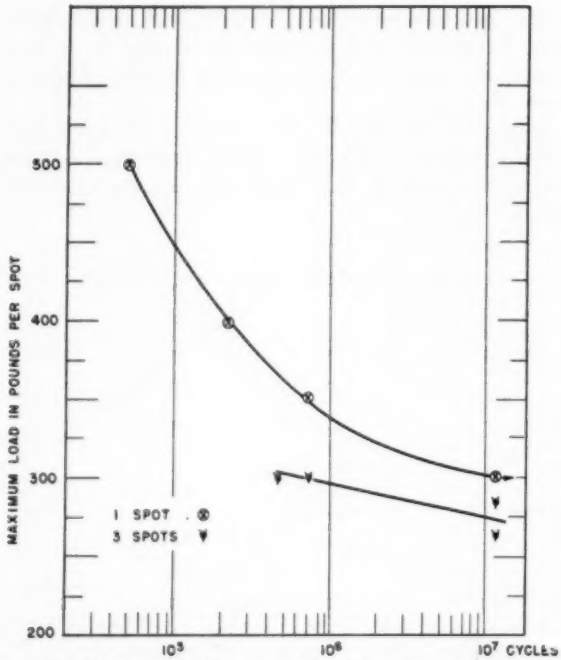

Fig. 28 Hydrostatically treated 0.024-in. sheet using 1/8-in. tip and 400,000 psi hydrostatic pressure on the spot welds

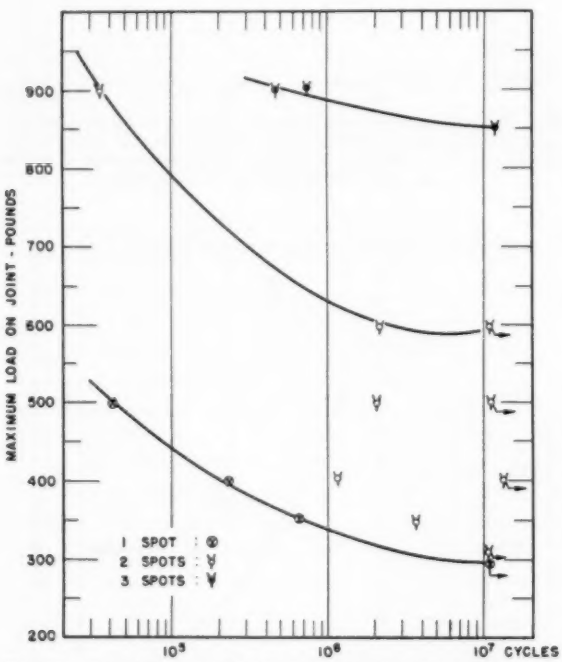

Fig. 29 Comparison of fatigue properties for hydrostatically treated 1-, 2- and 3-spot specimens in 0.024 in. stainless steel spot-welded sheet (1/8-in. tip and 400,000 psi compression)

Obviously, both the sheet thickness and the number of spot welds influence the degree of improvement to fatigue properties obtained by hydrostatic treatment. This observation is shown by Fig. 30. The effect of thickness is to be expected since the fatigue failure takes place *in the sheet* adjacent to the spot weld as

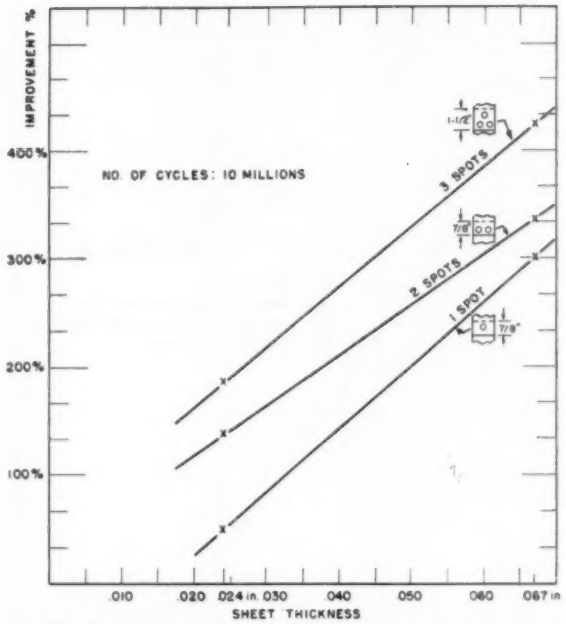

Fig. 30 Percentage of improvement due to 400,000 psi hydrostatic compression in relation to sheet thickness and number of spots (1/8-in. tip for 0.024-in. sheet and 1/4-in. tip for 0.067-in. sheet)

demonstrated previously. The pronounced effect of the increased number of spots will be examined later.

Considering the foregoing results, the following observations can be made:

(1) Hydrostatic prestressing shows a definite improvement in fatigue properties over untreated specimens and exceeds that ever observed on other materials tested under similar conditions.

(2) Improvement seems to be a direct function of plate thickness as well as stiffness of the joint, as a result of the greater number of spot welds.

(3) It should be pointed out that the percentages of improvement are based on the comparison of the load which produced *no fatigue failure after more than* 10 million cycles. Even a greater degree of improvement would be evident if comparison is made on the basis of the number of cycles causing failure at a given load. For example, an *untreated* 3-spot, 0.067-in. thick specimen failed after 46,700 cycles when under an 1800-lb load, while a similarly loaded specimen hydrostatically compressed withstood 7,360,000 cycles (and failed in the grips).

(e) *The Effect of Variation of Applied Pressure in Hydrostatic Compression*

Treatment. All previously described prestressing tests were carried out at 400,000 psi. This hydrostatic prestressing was chosen after it was experimentally determined that the higher the hydrostatic pressure, the greater the improvement in fatigue characteristics of the spot-welded joints. This observation was made as follows: one, two and three spot samples were prestressed by applying direct loads of 5000, 10,000,

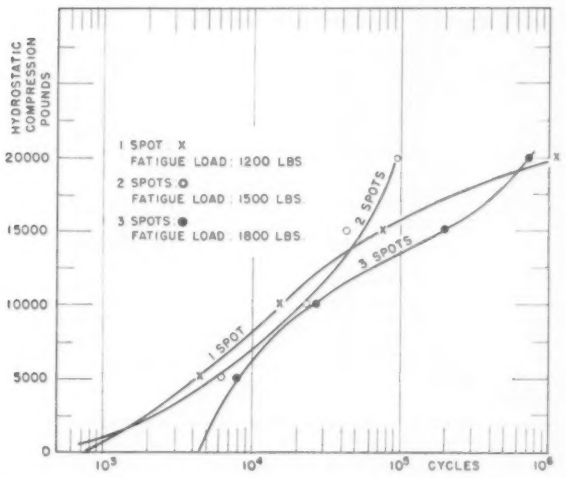

Fig. 31 Variations of applied pressure in hydrostatic compression treatment for 0.067 in. thick, 1 1/2 in. wide, stainless steel joint at above mentioned fatigue loads for each of 1-, 2- or 3- spot specimens

Load chosen to give between 10^5 to 10^6 cycles after compressions of 5000, 10,000, 15,000 and 20,000 lb which represent, with 1/4-in. tips, 100,000 200,000, 300,000 and 400,000 psi.

15,000 or 20,000 lb (using 1/4-in. spots, 0.067-in. sheet). These samples were then tested at arbitrarily selected loads expected to cause failure between 10^5 and 10^6 cycles. These loads were as follows: 1 spot, 1200 lb; 2 spots, 1500 lb; 3 spots, 1800 lb. The fatigue results of these variations in applied hydrostatic compression for the 0.067-in. spot-welded specimens are shown in Fig. 31. It is evident that a somewhat proportional increase in fatigue strength takes place as the hydrostatic compression load is increased.

As has been repeatedly pointed out, the fatigue failure originates not in the spot weld, but in the circular zone around the spot, obviously affected by the heat of welding. It is reasonable to assume that the steel *in this zone* is in the fully or partially annealed condition, while the rest of the material, farther away from the weld, is still half hard. Under the pressure of hydrostatic compression the *annealed zone* becomes subject to radial expansion with the resultant compressive stresses. Therefore, the higher the initial compression, the higher the compressive stresses and the greater the improvement to the fatigue characteristics.

Other factors besides the degree of prestressing may be of consequence, such as: (1) The shape of the compression tip; (2) the size of the tip in relation to the size of the spot; (3) the effectiveness of "annealing" action, including the area of the annealed zone.

(f) *Larger Hydrostatic Compression Area Tests (Compressing the Heat-Affected Zone)*

A few tests on the effect of an enlarged tip size, to include compression of the heat-affected zone were carried out. The size of the tip used was 5/16 in. diam instead of the usual 1/4-in. tip. The area compressed was believed to include most of the heat-affected zone. The results are reported in Figs. 23 through 25 and no startling or clearly established improvement can be observed through the enlargement of the compression tip by this small amount. In fact, the results were inconclusive since slightly better results were obtained for the 1-spot specimen, and poorer results were evident in the 2-spot specimen and the 3-spot specimen indicating an appreciable difference in results. Further tests are needed to establish firm recommendations.

(g) *Simple Compression Tests (Without Hydrostatic Treatment)*

It should be conceded that the procedure described herein for applying hydrostatic compression would be awkward in production. Hence, in addition to the hydrostatically compressed specimens, further tests were made on the 0.067-in. thick material whereby the 400,000 psi compression was applied directly on both sides of the spot without the specimens being tightly clamped in the compression box (Fig. 6). The sheets were simply held in place while the 1/4-in. diam tips were compressing the spots. This treatment resulted in plainly seen lateral flow of metal around the spots creating an encircling ridge. Although no exhaustive test program was carried out, sufficient information has been obtained to conclude that less improvement in the fatigue values is to be expected when spots are subjected to this method of prestressing, rather than by the regular hydrostatic compression as previously described. Yet it is important to note that even with this simple

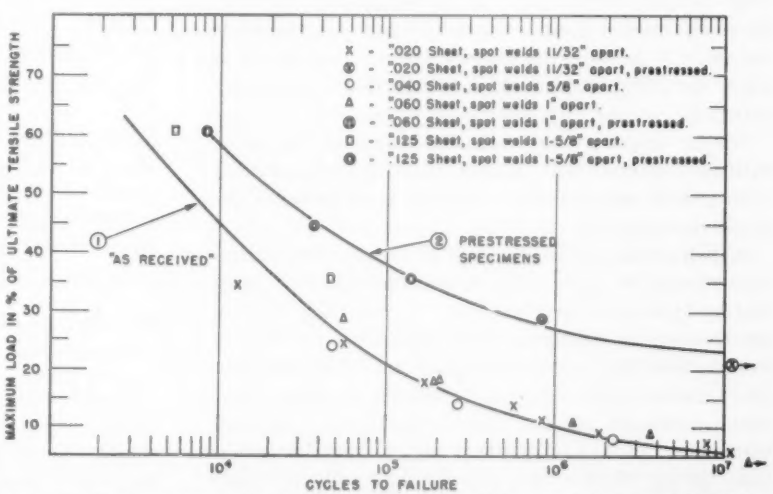
X - .020 Sheet, spot welds 11/32" apart.
● - .020 Sheet, spot welds 11/32" apart, prestressed.
○ - .040 Sheet, spot welds 5/8" apart.
Δ - .060 Sheet, spot welds 1" apart.
▲ - .060 Sheet, spot welds 1" apart, prestressed.
□ - .125 Sheet, spot welds 1-5/8" apart.
■ - .125 Sheet, spot welds 1-5/8" apart, prestressed.
① "AS RECEIVED"
② PRESTRESSED SPECIMENS
MAXIMUM LOAD IN % OF ULTIMATE TENSILE STRENGTH
70
60
50
40
30
20
10
10^4
10^5
10^6
10^7
CYCLES TO FAILURE

Fig. 32 Fatigue strengths of single-row, spot-welded, stainless steel lap-joint specimens. Results of the investigation conducted at Battelle Memorial Institute and sponsored by International Nickel Co., Inc.

Table 3—Progressive Loading of Specimens After Hydrostatic Compression Treatment

Specimen	*Max. load, lb*	*Max. load, lbs/spot*	*Cycles to failure*	*Remarks*
2 spot	600	300	12,778,900	Did not fail
0.067 in.	800	400	12,537,300	Did not fail
thick, 1/8-in.	1000	500	9,557,200	Did not fail
	1100	550	5,890,300	Did not fail
spacing	1200	600	2,204,600	Fracture
Total fatigue load of similar untreated specimens at 10 million cycles: *320* lb				
Total fatigue load of treated specimens at 10 million cycles: *1400* lb				
3 spot	500	167	12,778,900	Did not fail
0.067 in.	1200	400	12,537,300	Did not fail
	1400	467	9,557,200	Did not fail
	1500	500	5,890,300	Did not fail
thick, 5/8 in.	1600	534	3,938,900	Did not fail
	1700	567	2,355,100	Did not fail
spacing	1800	600	2,196,500	Did not fail
	1900	634	1,972,600	Did not fail
	2000	667	4,275,500	Fracture
Total fatigue load of similar untreated specimens at 10 million cycles: *845* lb				
Total fatigue load of treated specimens at 10 million cycles: *1800* lb				

compression the results on 1-, 2- and 3-spot samples indicated a considerable improvement over untreated, i.e., uncompressed samples of the same material. Figures 23, 24 and 25 all contain data which illustrates this improvement.

(*h*) *Prestressing Joints by Tension*

Another method of prestressing the spot-welded joint which was investigated early in this program was using a tensile stress. This method consisted of prestressing the material to the order of 75% of its ultimate (static) strength by a tensile machine. This application of tensile stress should result in a more even distribution of subsequent fatigue stresses among the spots, thereby improving its fatigue characteristics. Although such a prestressing treatment is not practical, the results of this investigation, given in Fig. 32, are interesting. This figure includes data on fatigue strength of a number of single-rowed joints in sheets of different thickness, both as-welded and prestressed. It may be noted that: (1) joints in different sheet thicknesses show roughly comparable fatigue strengths in per cent of static strengths up to and including 0.125-in. sheets (the thickest sheet that was investigated); (2) prestressing brought about roughly the same improvement for joints of different thicknesses. This increase was as much as 400% in strength at 10 million cycles (by extrapolation and interpolation of data).

Similar improvement was also recorded for joints with two rows of spots; in fact, the latter tests showed even greater improvement than has been found in the single-row samples.

A distinction not yet illustrated by experimental results should be made between prestressing by tension and by hydrostatic compression. As the term implies, prestressing by tension consists of plastic straining *in one direction only*, namely, along the axis of the samples. The fatigue stresses were also applied in the same direction. Although marked improvement was observed from this method of prestraining, it remains to be investigated whether this improvement will take place *regardless* of the direction of fatigue stress. On the other hand, hydrostatic compression is applied in *all directions* and it would be expected that the improvement in the fatigue characteristics will be less dependent upon the direction of applied fatigue stresses.

(*i*) *Effect of Stressing by Peening on Spot-Welded Samples*

Another series of exploratory tests were carried out on samples which were subject to peening by a special peening tool prior to testing in fatigue. The peening was done on the heat-affected zones of the sheet in the areas where fatigue cracks are known to originate. This method of conditioning the metal also resulted in the improvement of fatigue strength of the joints, but to a lesser degree than was obtained by either prestressing by tension or by hydrostatic compression. Since only a few peening tests were conducted, this method should be further investigated.

(*j*) *Fatigue Testing with Guiding Sheaths*

At the beginning of the investigation it was realized that because of the geometry of the test samples, a certain amount of bending was inevitable during testing in fatigue. To minimize or, if possible, to eliminate bending stresses, samples were tested with "guiding sheaths" so that the loading of the samples was very nearly axial. This method of testing showed only a slight improvement in the values for fatigue strength (Figures 20 and 23) compared with those without guiding sheaths (as-received). The improvement is in no way comparable with that achieved by hydrostatic or even simple compression methods.

(*k*) *Progressive Loading or "Training" of Specimens After Hydrostatic Compression*

In determining the fatigue load of treated specimens, certain loads were applied for a duration of approximately 10 million cycles. When no fracture occurred, the same samples were subject to higher loads (or "trained") until fracture occurred. Details are given in Table 3.

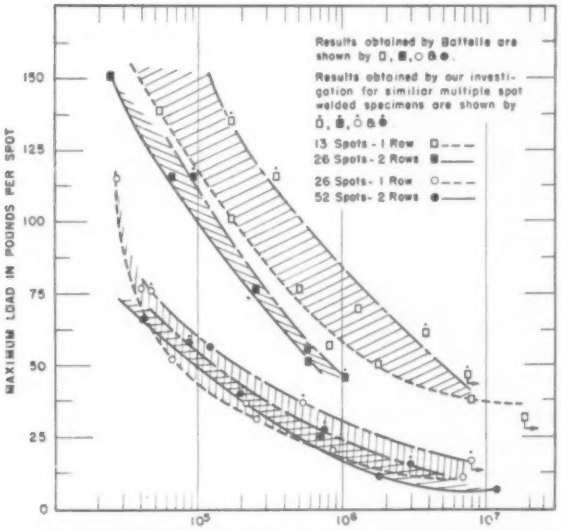

Fig. 33 Verification of fatigue test results in 0.024-in. thick joints of stainless steel

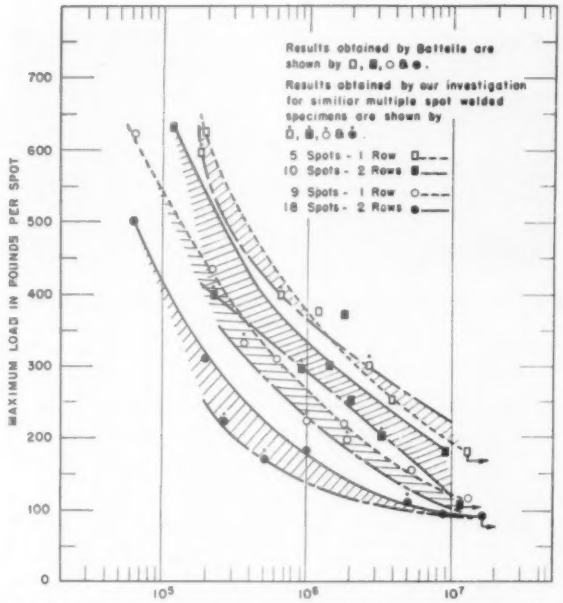

Fig. 34 Verification of fatigue test results in 0.067-in. thick joints of stainless steel

It will be remembered that treated samples with 2 spots lasted about 10 million cycles at 1400 lb total load (see Fig. 24). Even though failure did not occur at 10 million cycles the shape of the curve beyond this number of cycles cannot be established on the basis of conducted tests. Consequently, it is not possible to state whether long life (large number of cycles) at lower loading adversely affected the fatigue characteristics. All that can be said is that the large number of cycles at lower loads did not alter the beneficial effect of prestressing. The same observations apply to 3 spot samples in 0.067-in. thick material.

Following the above results on improvement of joints in fatigue testing after the hydrostatic compression treatment, a few hypotheses may be elaborated on for tentative explanation, but none would seem too conclusive. Crystalline reorientation by cold compression, release of internal stresses during spot welding, setup of more favorably oriented stresses around the spot, stress orientation in the interface of the joint between the nugget and adjacent heat-affected zone, and limitation of bending on the spot are all intermingled effective factors.

In any event, triaxial stresses seem to be redistributed from a haphazard to a better pattern, but not necessarily one productive of optimum properties.

(*l*) *Verification of Multiple Spot-Welded Joints*

Tests were performed to verify curves obtained by Battelle Memorial Institute* for fatigue characteristics of stainless steel sheet with multiple-spot-welded joints. The summary of the results is shown in Figs. 33 and 34 with all values presented in pound per spot values. This spot checking of the *S–N* curves agrees quite substantially for the 0.067-in. thick joints; however, consistently higher values were found for the 0.024-in. thick specimens.

In connection with these verification results it should be pointed out that some specimens did not have the same number of spots. Other variables, such as thickness of material, etc., account for the slight differences in results.

The following observations can be made from these data: (1) The lesser number of spots produce a higher fatigue ratio. (2) For each thickness, the improvement with a lesser number of spots toward a higher fatigue ratio is steeper for one row than for two rows of joints.

(*m*) *Hydrostatic Compression on Multiple-Spot Joints*

Difficulties in hydrostatically compressing multiple-spot-welded specimens were brought about by not being able to prevent lateral flow toward the edge. When the compression dies were fitted with a striated strip which was forced against the edge of the joint, the undue deformation could not occur.

Three-spot specimens were machined from 5- and 10-spot samples by reducing the width of the plate to $3^1/_2$ in., thereby removing the end spots of the 1- and 2-row specimens as shown in Fig. 35. The following results were obtained from these tests:

	As-received specimen Spots, no. of	*Hydrostatically compressed specimen 3 in one row*
Load, max	1,200	4,500
Cycles to rupture, no. of	7,286,800	Did not rupture after 10,000,000 cycles

* Work sponsored by the International Nickel Co.

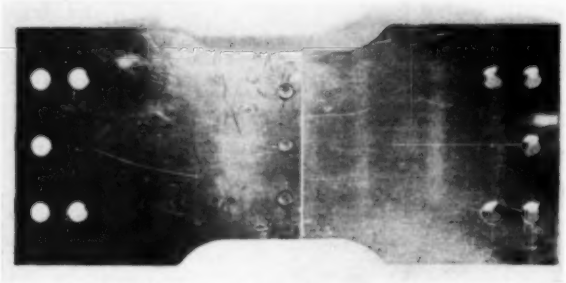

Fig. 35 Machined specimen from multiple-spot-welded samples

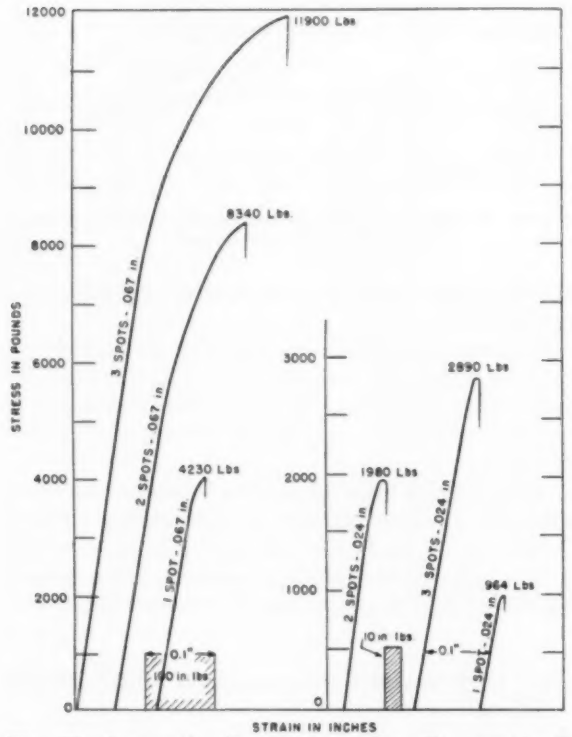

Fig. 36 Automatic diagram recording "to rupture." Energy absorption evaluation of 1-, 2- 3-spot, 0.024- and 0.067-in. thick stainless steel joints

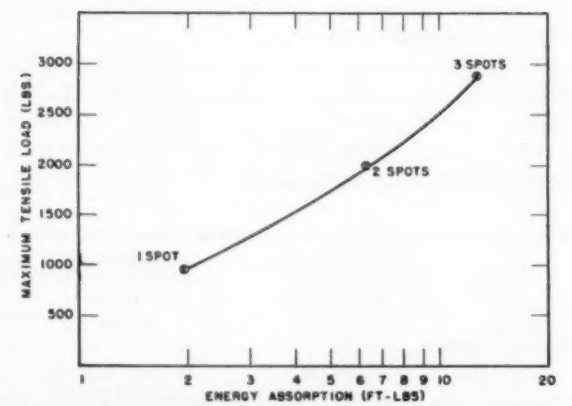

Fig. 37 Relationship between energy absorption and strength in 0.024-in. stainless steel spot-welded sheet

Table 4—Energy Absorption for Rupture Evaluation of Static Diagram Area

Gage, in.	*No. of spots*	*—Energy Absorption— (a) In.-lb*	*Ft-lb (b)*	*Maximum tensile load, lb*	*Ratio b/a*
0.024	1	23	1.9	964	42.
0.024	2	76	6.3	1,980	26.
0.024	3	145	12.8	2,890	20.
0.067	1	300	25.0	4,230	14.0
0.067	2	802	66.7	8,340	10.
0.067	3	2025*	168.7	11,900	6.0

All above are results of two tests.
* Approximation due to grip failure.

Figure 11 shows a comparison of other multiple-spot joints on a pound per spot basis with variations in number of spots, specimen width, distance between spots and rows for 0.067 in., untreated spot-welded specimens.

From the tests on hydrostatically treated 0.067-in. thick, multiple-spot-welded specimens, the comparison between spot and row spacing, the following observations can be made:

1. For effective hydrostatic compression of a spot, sufficient adjacent sheet material is required to prevent any lateral flow and avoid damage to the next spot previously compressed.

2. Interspot spacing is of primary importance if maximum advantage is to be realized from the hydrostatic compression treatment. As an example, when the spacings between the spots was $^1/_2$ in., the improvement gained from hydrostatic compression treatment was only 50%; however, when this spacing was $^5/_8$ in. between spots, 337% improvement in fatigue properties was realized from the prestressing treatment.

(n) Maximum Energy Absorption

Energy absorption is defined as the area under the stress-strain diagram in tensile testing. Such tests have been performed on all types of specimens and automatic recording diagrams have been made.

Figure 36 shows a reproduction of such diagrams for the 1-, 2- and 3-spot specimens in the 0.024 and 0.067

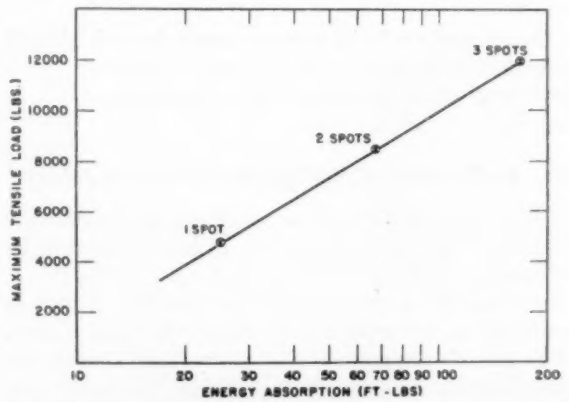

Fig. 38 Relationship between energy absorption and strength in 0.067-in. stainless steel spot-welded sheet

in. thicknesses. One typical diagram in each case has been chosen although the figures presented in Table 4 shows the energy calculations and maximum tensile loads for each of the six types of specimens investigated. Data from this table are reproduced in Figs. 37 and 38 and show the relationship between energy absorption and strength to be very nearly directly proportional.

The following observations can be made from these data:

1. In all cases energy absorption values are somewhat low as failure always occurred by shearing in the spot which, because of its cast structure, possesses a very limited plastic deformation.

2. Maximum tensile loads give some indication of probable energy absorption values for rupture.

6. SUMMARY

(*a*) For stainless steel sheet as-spot welded, as the number of spots per sample is increased, the load (per spot) to cause localized failure through fatigue is decreased.

Also, the course of the fatigue curve becomes steeper as the number of spots is increased and as the thickness of the sheet is increased.

(*b*) The location of the fatigue crack in the as-spot-welded tests was never in the weld button but in the heat-affected zone of the parent (sheet) metal. There is no correlation between fatigue and shear strength. A comparison of tensile (shear) and fatigue strength is not warranted since in one case the values are representative of cast metal (weld nugget) and in the other case the values represent the resistance of heat-affected (annealed) sheet material to failure through fatigue. It has been confirmed, however, that the strength of the spot-welded joints tested in fatigue when compared to the strength of similar joints tested in straight tension is very low.

(*c*) Hydrostatic prestressing shows a definite improvement in fatigue properties over untreated specimens and this improvement exceeds that observed on other materials tested under similar conditions. This is the case regardless of the number of spot welds prestressed in one treatment.

(*d*) Simple compression of the spot welds produced a considerable improvement in fatigue over uncompressed samples of the same material.

(*e*) Similar improvement in fatigue characteristics could also be gained by prestressing by tension or peening.

ACKNOWLEDGMENTS

The authors wish to express their appreciation to the Budd Co. of Philadelphia, Pa., for their cooperation in supplying the sheet material for testing and for performing the spot-welding operations in accordance with their established practice. We wish to acknowledge our indebtedness to D. W. McDowell, Jr., for the skillful condensation of voluminous manuscript and its critical review.

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Performance of Weldments and Prime Plate of ABS-B Steel*

Evaluation of weldments made of ABS Grade B steel with different electrodes using the Explosion Bulge Test

by W. S. Pellini and E. W. Eschbacher

Abstract

The relative performance of G180 and E6010 ABS-B ship plate weldments and prime plate was evaluated by the Explosion Bulge test. The prime plate loses its ability to develop extensive deformation prior to fracture in the range of −60 to −80° F; the G180 weldment develops a similar loss in the range of +20 to 0° F and the E6010 weldment in the range of +40 to 0° F. The effects of various types of defects including arc-strikes, porosity and partial penetration were investigated. It is shown that in the service temperature range of 20 to 60° F only sharp, cracklike defects such as developed by arc-strikes are sufficiently critical to eliminate extensive plastic deformation of weldments prior to failure.

The effects of shot peening of ABS-B steel is demonstrated to be detrimental with respect to the resistance of this steel to initiation and propagation of brittle fractures. Wrought iron considered as a possible material for crack arrester straps is demonstrated to be less resistant to brittle fracture than ABS-B steels.

INTRODUCTION

THE "Rules for Building and Classing Steel Vessels" issued by the American Bureau of Shipping specify the use of Class B* steel for plates over 1/2 and up to 1 in. thickness. In view of the importance of ABS-B steel to present and future construction of welded ships, the Ship Structure Committee has undertaken an extensive research program aimed at determining the performance characteristics of the prime plate and weldments. This report summarizes the results of various investigations conducted at the Naval Research Laboratory. The following aspects of the performance of prime plate and weldments were investigated.

1. Effect of sharp, cracklike defects on the performance of prime plate and cor-

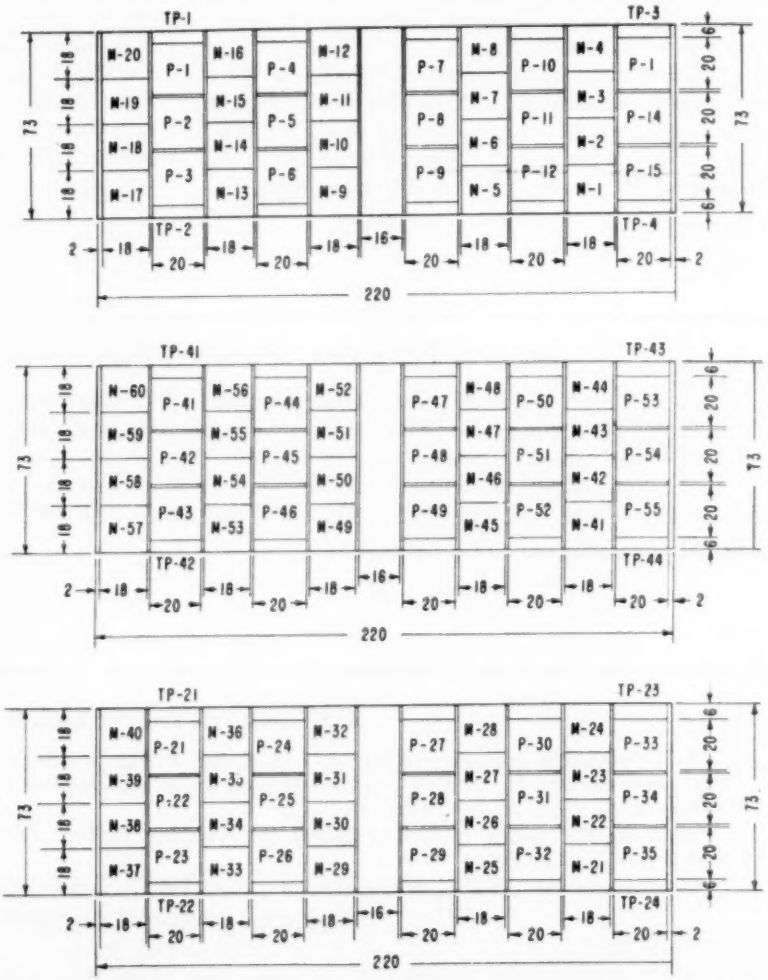

Fig. 1 Sectioning diagrams for the ABS-B steel plates used for weldment studies

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Scheduled for presentation at the Thirty-Fifth National Fall Meeting, AWS, to be held in Chicago, Ill., Nov. 1-5, 1954.

The research described in this report was sponsored by the Ship Structure Committee as part of its research program. The work was conducted under the general supervision of the Explosion Test Advisory Committee of the Ship Structure Committee.

The opinions expressed herein are those of the authors and do not necessarily represent those of the Ship Structure Committee, the Explosion Test Advisory Committee or of the Department of the Navy.

* The specification is based on chemical analysis as follows: C 0.23% max, Mn 0.60–0.90% P 0.04% max, and S 0.05% max; Si not specified.

Table 1

Explosion Bulge test plates (see Fig. 1)

G180	*R6010*	*Prime*
P-21	P-42	P-1
P-22	P-43	P-2
P-23	P-44	P-3
P-24	P-45	P-4
P-25	P-46	P-5
P-26	P-47	P-6
P-27	P-48	P-7
P-29	P-49	P-8
P-30	P-50	P-9
P-31	P-51	P-10
P-32	P-52	P-11
P-33	P-53	P-12
P-34	P-54	P-13
	P-55	P-14

Charpy V and drop weight test plates (see Fig. 1)

P1 M30 M50

relation to Charpy V transition data.

2. Effect of shot peening the prime plate surface. (Shot peening had been suggested as a possible method of increasing the resistance to fracture of ship plate.)

3. Comparison of the relative fracture resistance of ABS-B ship plate with wrought iron plate. (Wrought iron had been suggested for crack arrester strap inserts.)

4. Effects of partial penetration weld defects on the performance of E6010 VV butt weldments of ABS-B ship plate with comparison to the effects of sharp crack defects such as arc-strikes.

5. Comparison of the performance of E6010 and G180 VV† butt weldments.

The performance of weldments was investigated by the Explosion Bulge method. The relative fracture resistance of prime plate, shot-peened plate and wrought iron plate was investigated by the drop weight method.

MATERIAL

The material for Explosion Bulge tests of E6010 and G180 weldments and comparison prime plate was obtained from three 73 x 220-in. plates of 1 in. thickness, rolled from one heat. Figure 1 illustrates the cutting procedures. The origin of the various weldments and prime plate specimens listed in Table 1 may be deduced from the figure. The remaining material was utilized for Direct Explosion tests to be reported separately.[1]

The material for the partial penetration weld studies was obtained from a $^3/_4$-in. thick plate rolled from a separate heat. The material for the evaluation of shot peening was taken from a 1-in. plate also of a separate heat. Except for the case of the three plates rolled from one heat the material was taken directly from plate stock of the Philadelphia Naval Shipyard. The wrought iron plate was obtained from a commercial source.

† E7016 type conforming to MIL SPEC-E986A (Ships).

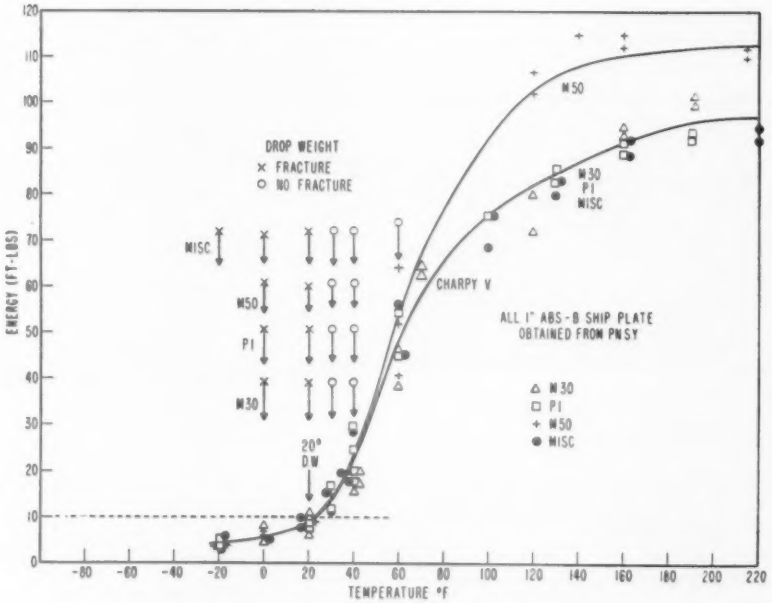

Fig. 2 Charpy V transition curves and drop weight test data

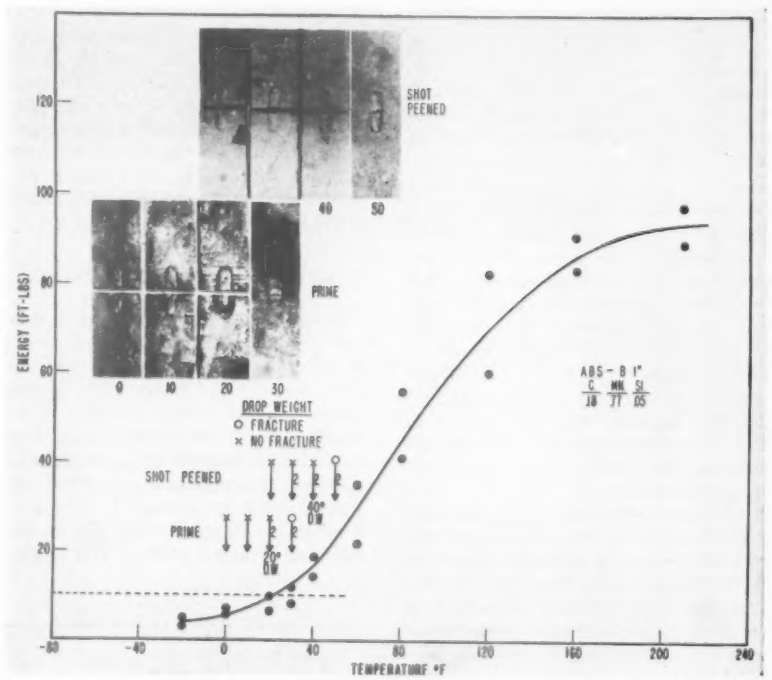

Fig. 3 Charpy V transition curve for ABS-B steel used in shop peening investigation. Drop weight test transition temperature is raised 20° F as the result of shot peening the surface

Table 2—Chemistry of Various ABS-B Plates

Plate	*Thickness, in.*	*Source*	*C, %*	*Mn, %*	*Si, %*	*P, %*	*S, %*
P1	1	PNSY (Special)	0.20	0.72	0.04	0.018	0.053
M30	1	PNSY (Special)	0.19	0.76	0.04	0.015	0.043
M50	1	PNSY (Special)	0.19	0.77	0.04	0.012	0.043
Miscellaneous	1	PNSY (Stock)	0.22	0.81	0.04	0.018	0.047
Peening test	1	PNSY (Stock)	0.18	0.77	0.05	0.015	0.040
Partial penetration	$^3/_4$	PNSY (Stock)	0.19	0.69	0.04	0.010	0.015

The chemical analyses of the various plates are listed in Table 2.

CHARPY V AND DROP WEIGHT TESTS OF PRIME PLATE

The Charpy V energy transition data for the three 1-in. plates rolled from one heat are presented in Fig. 2. The M50 and M30 material was obtained from the center regions of two separate plates and the P1 material from the edge of the remaining plate. Material from a miscellaneous plate of 1 in. thickness obtained from yard stock is included for comparison. It is noted that the test points obtained for the various samples permit drawing of only one curve at the lower portion of the transition range. Figure 3 presents the Charpy V transition data for the 1-in. thick material used for the shot peening investigation. The transition curve for this plate is closely similar to the curves presented in Fig. 2 for the other 1-in. plates.

Drop weight tests were performed in accordance with procedures described in previous reports.[2,3] Briefly, a hard-surfacing weld bead is placed at the center of a $3^1/_2$- x 14-in. test piece (see Fig. 3, photograph inserts) and a notch is cut across the bead to facilitate cracking. The specimen is cooled to test temperature, placed across a 12-in. span and then loaded by the fall of a weight which impacts at midspan. The brittle weld cracks on loading, thus developing a sharp cleavage crack notch (synthetic sharp crack defect). The test is aimed at determining the highest temperature at which the minute amount of deformation, corresponding to 2 deg of bend in the presence of the sharp cracklike defect, results in brittle fracture of the steel. The subject temperature is termed the drop weight nil ductility transition and denotes that at and below this temperature the steel has no appreciable ductility in the presence of sharp crack defects.

The drop weight test data presented in Figs. 2 and 3 show that the highest fracture temperature of each of the four 1-in. thick ABS-B steels was 20° F. The Charpy V energy at 20° F is 8 to 10 ft-lb for all of the steels which is in agreement with the general relationship of the drop weight nil ductility transition temperature and Charpy V energy established previously for semikilled and rimmed mild steels of ABS-A type.[5, 3] Briefly, the drop weight nil ductility transition always occurs at temperatures within the range of Charpy V 3–10 ft-lb and most frequently at temperatures corresponding to Charpy V 5–8 ft-lb. Tests to date of approximately 40 ABS-A ship plate steels including steels of war time manufacture and steels taken from fractured ships have indicated drop weight nil ductility transition temperatures ranging from 0 to 60° F and with greatest frequency at 20 to 30° F. Thus, the four ABS-B steels cannot be considered superior to the majority of the steels tested previously which conform to the present ABS-A classification. This statement does not imply that the quality range of the ABS-B type is the same as that of ABS-A type, since it is not known if with extensive sampling the ABS-B steels will cover a similar range of 0 to 60° F. Information of this type would be highly desirable.

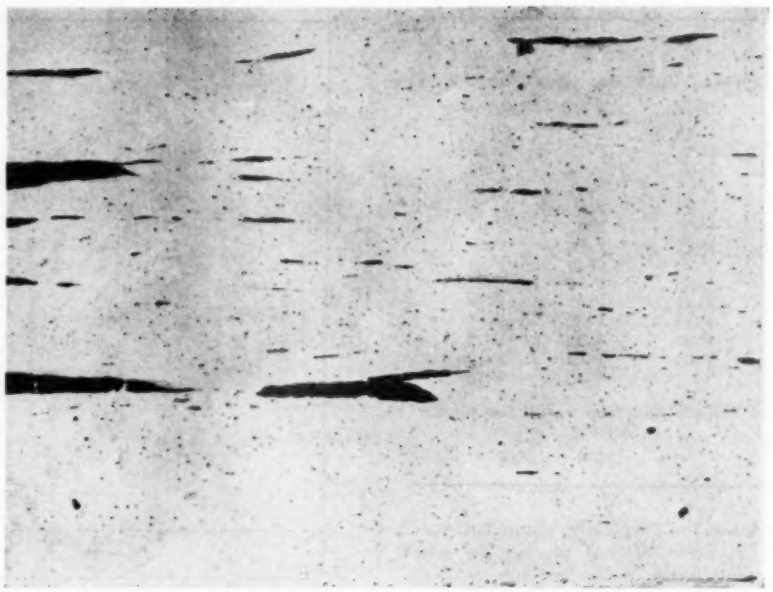

Fig. 4 Microstructure of commercial wrought iron. × *50*

EFFECTS OF SHOT PEENING

Shot peening of ship plate and welds has been suggested as a possible means of increasing the resistance to fracture of ship structures. While shot peening affects only the surface material, it was considered that the effects of the treatment could be appreciable inasmuch as the initiation and propagation of brittle fracture is strongly controlled by minute amounts of shearing (shear lip) at free surfaces. Previous work at this Laboratory[4] disclosed that shear lips of 0.010 to 0.020 in. thickness were sufficient to prevent propagation of fractures.

The drop weight test was used to evaluate the effects of shot peening. Drop weight test specimens were prepared from ABS-B ship plate of 1 in. thickness and divided into two groups. One group was forwarded to a commercial shot-peening concern. Shot peening was accomplished with $^1/_{16}$-in. diam steel shot using a $^1/_4$- x 3-in. nozzle operating at 100 psi. The nozzle was held 4 in. from the plate and the surfaces were peened uniformly for 5 min. Both sides of the specimens were treated in this manner. It should be noted that the brittle crack-starting weld was placed on the specimen prior to peening. Approximately three weeks elapsed between the time of peening and testing of the drop weight specimens. This fact is of interest from a standpoint of strain aging which may be expected to have occurred in the cold-worked surface material.

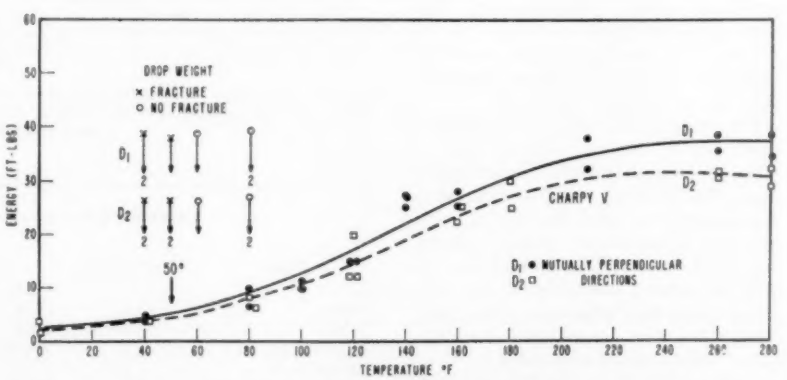

Fig. 5 Charpy V and drop weight test data for commercial wrought iron

Figure 3 presents the results of the drop weight tests of shot-peened material in comparison to the prime material which was described in the previous section as equivalent to the three other 1-in. thick ABS-B plates. It is observed that shot peening raised the fracture temperature to 40° F indicating a distinct impairment of this steel due to cold working the surface metal.

It is concluded that shot peening adversely affects the properties of the surface material of ship plates with consequent decrease in the resistance to the initiation and propagation of brittle fracture. In this respect it should be noted that peening of the last pass of E6010 VV butt weldments of 1-in. thick ABS-B steel was demonstrated[5] to be highly detrimental to the performance of the weldments due to cold-work embrittlement of the weld metal.

COMPARISON WITH WROUGHT IRON

Wrought iron has been suggested as a possible material for use in crack arrester straps. Obviously, for such use it should be demonstrated to exceed the fracture resistance of ABS-B ship plate by an appreciable margin.

The wrought iron used for this investigation represents material from present commercial production. It was obtained in the form of 1-in. thick rolled plate. The analysis and tensile properties were determined to be as follows:

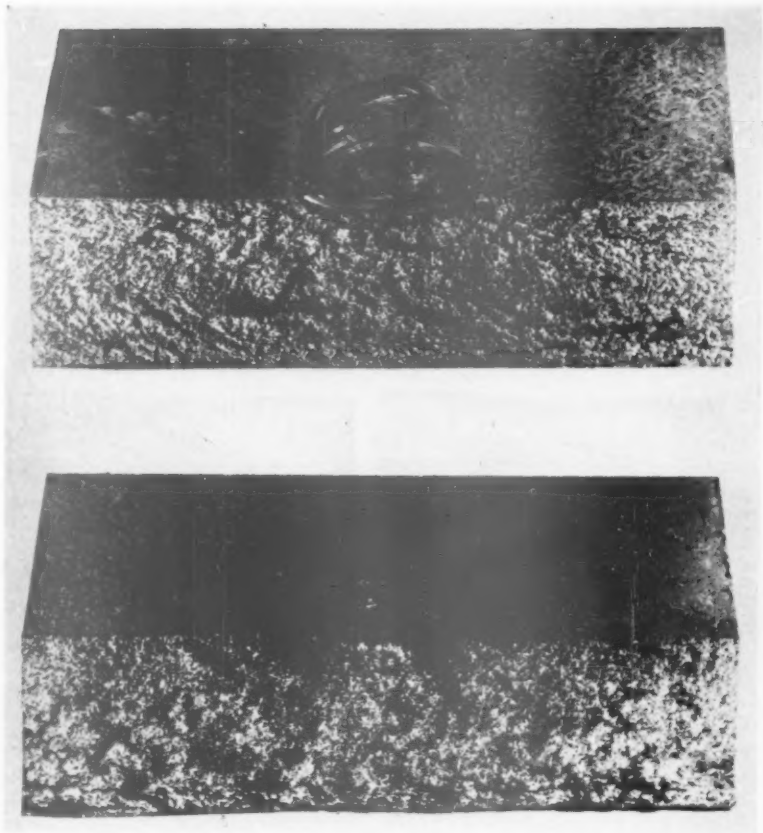

Fig. 6 Fracture surfaces of ship plate steel (top) and of wrought iron (bottom); broken halves of drop weight test specimens

C, %	0.03
Mn, %	0.02
Si, %	0.07

	Tensile strength, psi	*Yield strength, psi*	*Elongation % in 2 in.*	*% Reduction area, %*
D1*	51,000	26,500	16.5	22.0
D2	47,000	26,700	12.0	22.7

* D1 and D2 represent two mutually perpendicular directions; direction of rolling not known.

Microstructures in two mutually perpendicular directions are shown in Fig. 4. The slag stringer lengths were found to be approximately $^1/_8$-in. in actual length in both directions and considerable difficulty was encountered in attempting to deduce the direction of rolling. It is probable that the material was heavily cross-rolled.

Charpy V and drop weight test data for the D1 and D2 directions are presented in Fig. 5. The data indicate no significant difference due to direction of rolling and a resistance to fracture initiation (+ 50° F DWT) which corresponds to the poorest of the ABS-A type ship plates tested to date. This material is obviously not suited for use as crack arrester straps. Figure 6 illustrates the appearance of the drop weight fracture specimens of wrought iron in comparison to ship plate steel. In each case the fractures are of perfectly "square break" type.

COMPARISON OF PARTIAL PENETRATION AND SHARP CRACK DEFECTS

This investigation is part of a broad program of evaluation of the relative severity of weld defects on the performance of weldments which was instituted by the Ship Structure Committee. Six E6010 weldments of $^3/_4$-in. ABS-B ship plate were prepared by the Philadelphia Naval Shipyard. Three of these weldments were of conventional full penetration VV butt type and three were of partial penetration type featuring a $^1/_{16}$-in. gap at the center of the butt weld. One of the full penetration weldments was damaged by the application of arc-strikes as will be described.

Figure 7 illustrates the results of the various tests which were conducted. Two partial penetration welds and two full penetration welds were bulge tested at 55° F. The partial penetration welds withstood 8-9% TR (thickness reduction of plate) prior to failure, one of the full penetration welds withstood 31% TR prior to failure and the other withstood only 8% TR due to the presence of weld porosity. These results indicate a decrease in performance of approximately equal magnitude due to partial penetration and weld porosity. From a practical viewpoint of the performance of conventional ship structures neither defect may be construed to be critical, since relatively drastic deformation (8% thickness reduction) was required to produce failure.

Following these tests the effect of the presence of arc-strikes was investigated. Material was removed from the sides of a bulge test sample (as denoted by the dotted area *A* and *B* shown in Fig. 7) and arc-strikes were applied using a carbon-arc technique. This method produces repro-

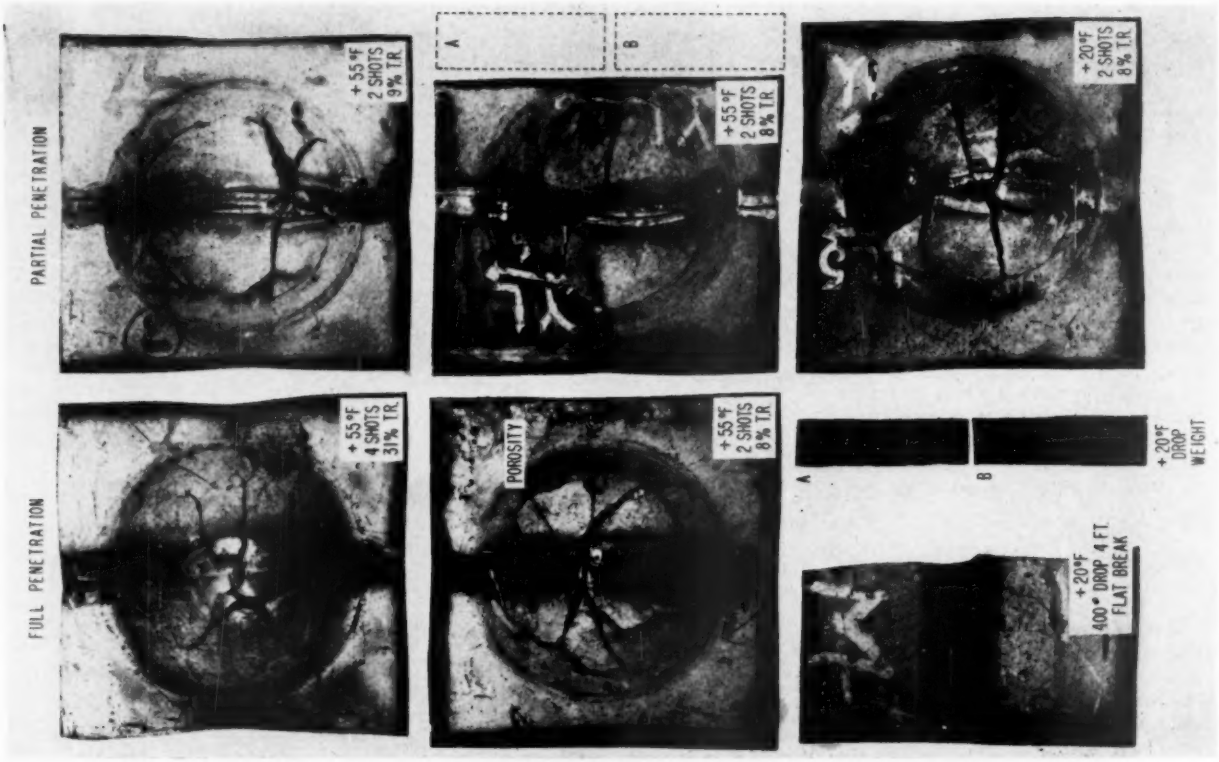

Fig. 7 Result of test illustrating the relative severity of arc-strikes and partial penetration welds

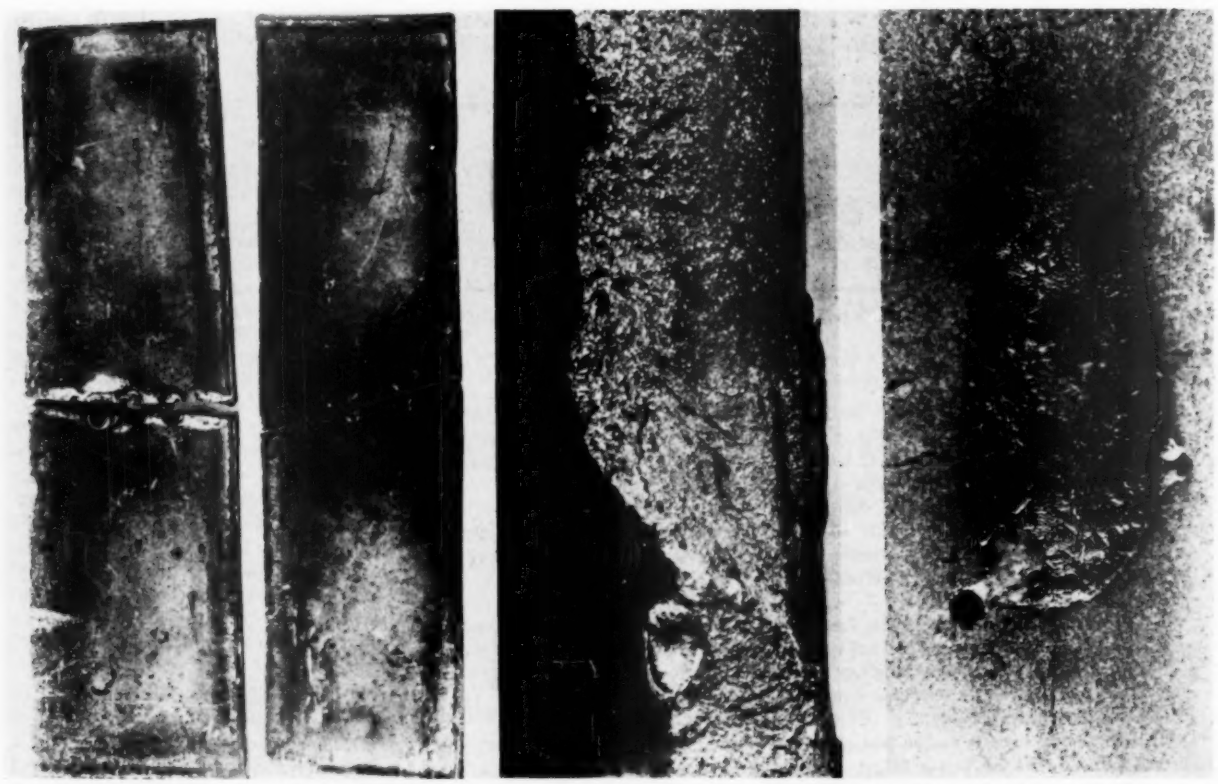

Fig. 8 (Left) "A" and "B" drop weight test pieces with arc-strike defects (see Fig. 7). (Center) Arc-strike origin of fracture in 20- x 20-in. weldment. (Right) Cracks associated with arc-strikes; the crater is approximately 1/8 x 1/4 in. actual size

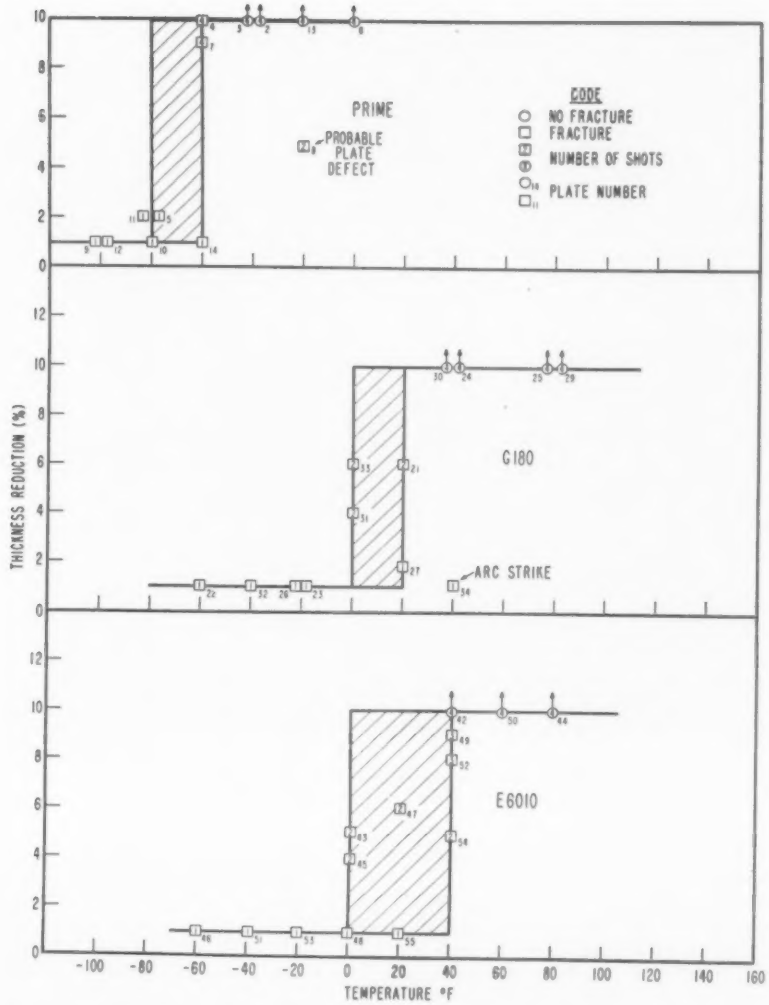

Fig. 9 Explosion Bulge Test ductility transitions of prime plate and weldments

ducible crack conditions adjacent to the arc-strike crater. The use of conventional E6010 electrodes to produce arc-strikes may also result in cracks but not reproducibly, i.e., the arc-strikes which result may or may not be associated with sharp cracks. The next step was to determine the critical temperature below which deformation is not possible in the presence of the sharp cracks associated with arc-strikes. This temperature may be determined from the Charpy V transition curve (below 10 ft-lb) or more expeditiously by means of the drop weight technique. Based on the previously described drop weight tests of ABS-B steel it was suspected that the critical temperature was approximately 20° F; accordingly, sections A and B were drop weight tested at 20° F. The resulting fractures indicated that this temperature was appropriate for the comparisons intended. Figure 8 (bottom) illustrates the type of cracks which are obtained with arc-strikes and the fractured drop weight specimens A and B (top).

The last remaining partial penetration weld was Explosion Bulge tested at 20° F and withstood 8% TR prior to failure, indicating similar performance as at +55° F. The last remaining full penetration weldment was damaged with carbon arc-strikes and tested at 20° F in the laboratory by dropping a 400-lb weight from a height of 4 ft. The weldment was supported at two ends and the weight impacted on the center of the span. Figure 7 (bottom left) illustrates the brittle break (no visible bending deformation) which resulted due to the presence of the arc strikes. Figure 8 (center) illustrates the fracture characteristics in detail; the arc-strike which initiated the failure of the full penetration weldment may be ob-

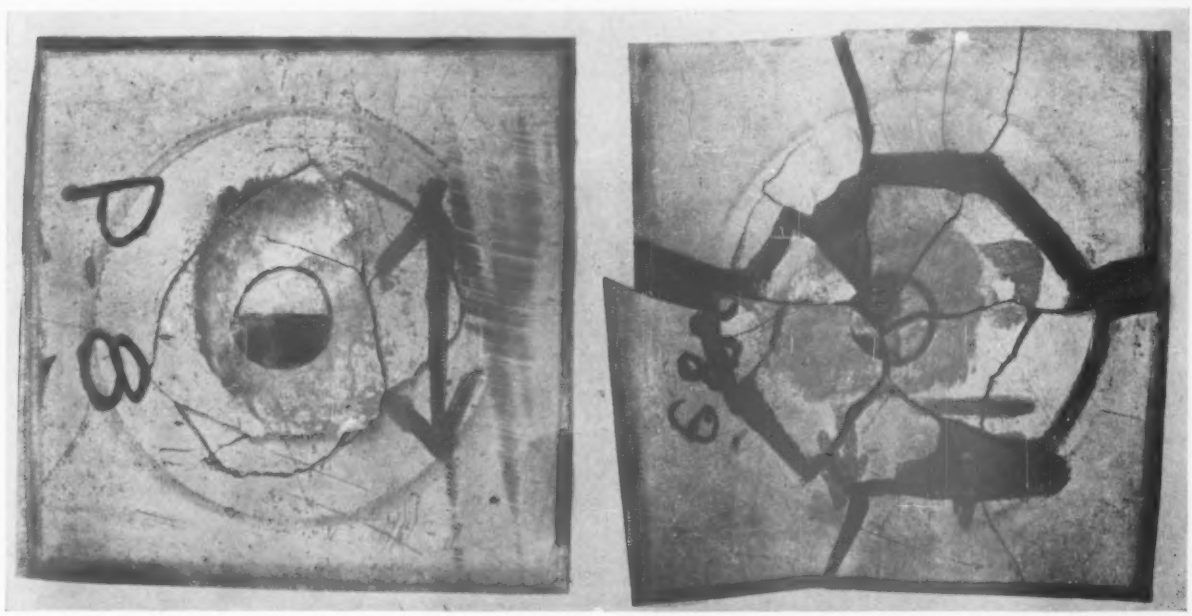

Fig. 10 Fractures of prime plate Bulge Test specimens (20- x 20-in. plates)

served at a position approximately 1-in. to the right of the weld. Actually, the presence of the weld (partial or complete penetration) was of no consequence inasmuch as the arc-strike was located away from the weld, i.e., the same result could have been obtained using a prime plate.

This comparison shows clearly that the defects to be feared in welded structures are those of sharp cracklike nature and that size of defects is not an index of severity. Arc strikes have been shown to be responsible for a number of ship failures. The NBS ship No. 52, for example, failed at 35° F (Charpy V of source plate 6–8 ft-lb) due to the presence of an arc-strike. Drop weight tests of the NBS ship No. 52 source plate resulted in fractures to +50° F (Charpy V 10 ft-lb).[3]

COMPARISON OF E6010 AND G180 WELDMENTS

Standard 20-x 20-in. double V butt weldments of E6010 and G180 welds were prepared by the Philadelphia Naval Shipyard. Explosion Bulge tests were conducted with the conventional 15-in. diam circular die. The weldments were tested with the weld reinforcement intact. Temperature control was obtained by refrigerating in cold temperature boxes of the dry-ice vapor type. The test temperatures are considered accurate to ±5° F. The explosive charge was 4 lb of Pentolite positioned at 15 in. from the plate. Unbroken test plates were returned to the cold cabinets for temperature re-equalization following each shot. Testing was discontinued after the fourth shot inasmuch as thickness reductions* of 14% were attained for plates which resisted four shots without fracture.

* Thickness reduction of the plate measured at the center of the bulge 1½ in. from the weld.

Fig. 11 Failure of P34, G180 weldment resulting from the presence of an accidental arc-strike. The insert shows small cracks in the arc-strike region

Figure 9 illustrates the bulge ductility transitions for the prime plate and for the weldments. The prime plate develops a sharp ductility transition in the range of −60 to −80° F. Figure 10 illustrates a typical fracture originating at the center of the bulge area and the anomalous off-center fracture of plate P-8 which was out-of-line with the remainder of the test series. The off-center point of fracture initiation indicates that a flaw condition was responsible for the poor performance

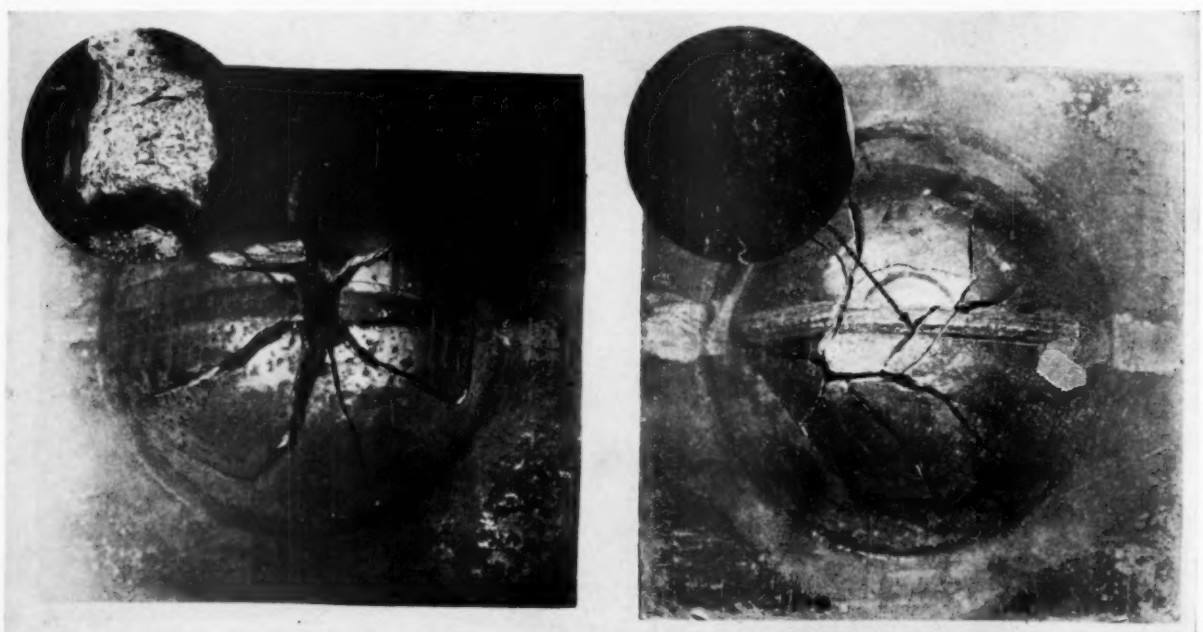

Fig. 12 Typical fractures of E6010 weldments (left) and G180 weldments (right)

of this plate. The nature of the flaw was not evident from a visual examination of the fracture.

The performance of the G180 weldments was essentially equivalent to that of the E6010 weldments at all temperatures, except possibly 40° F. It is noted that two G180 weldments developed 14% thickness reduction (four shots without failure) at 40° F while of four E6010 weldments only one equaled this performance; two of the E6010 weldments failed at 3 shots (8 and 9% TR) and one at 2 shots (5% TR).

The one shot (1% TR) failure of P34, G180, at 40° F is explained by the nature of the failure shown in Fig. 11 which shows no relation to the weld. The presence of an accidental arc-strike at the source of failure was responsible for this anomalous behavior. Several sharp, small cracks may be observed radiating from the arc strike which caused the initiation of failure. The arc strike was present in the weldment as received from the Philadelphia Naval Shipyard and was not noticed prior to testing despite critical x-ray and visual examination of all weldments on receipt at this Laboratory This is another excellent example of the critical nature of minute, accidental imperfections when present on steel which is susceptible to brittle fracture at service temperatures. Unless the notch toughness of the ship steels are improved to an extent sufficient to develop insensitivity to the presence of such accidental defects the benefits expected from high-quality welds will not always be realized in service. This fact is illustrated by the excellent performance of G180 weldments at 40° F in the absence of on-the-plate defects.

The typical fracture characteristics of G180 and E6010 weldments are illustrated in Fig. 12. The chevron markings indicated that the initiation of fracture occurred in the weld proper for the case of the E6010 weldments. In the case of the G180 the site of fracture initiation could not be established with certainty. In general the location indicated by the chevron markings was at fusion line area but without clear distinction as to weld or HAZ side of this general area.

It should not be concluded on the basis of these tests that there is no advantage to the use of G180 low-hydrogen electrodes over the E6010 cellulosic type. These data are specific to weldments prepared under laboratory conditions and indicate that the two weldments made under such optimum conditions are essentially equivalent. The low-hydrogen electrodes were developed to mitigate fissuring and other cracklike defects which are developed when welding is performed with deviations from optimum conditions common to field use. The known effectiveness of low-hydrogen electrodes in this respect commend their use particularly when the steel to be welded is sensitive to the presence of crack-like defects (as demonstrated) at temperatures of service use.

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Underwater Metallic Arc Welding

An investigation of operating characteristics of different water proofing coatings on electrodes in underwater welding

by Roger C. Waugh and Otto P. Eberlein

AMAZING strides have been made in the theoretical approach to welding in the past decade. The welding engineer today stands equipped with increasing knowledge of the physical and metallurgical mechanisms of such phenomena as the mode of metal transfer through the arc and the effect of various coating components in relation to arc stability and weld penetration. These represent two of the many factors integral to welding.

Mr. Waugh and **Mr. Eberlein** graduated from the Cornell University School of Metallurgical Engineering in June, 1954. Mr. Waugh is presently employed as junior metallurgist at the Oak Ridge National Laboratory. Mr. Eberlein worked for Lincoln Electric Company and is now serving in the U. S. Navy.

Abstracted from the *Cornell Engineer*, May 1954. Paper awarded first prize in the 1953-54 A. F. Davis Undergraduate Welding Award Competition.

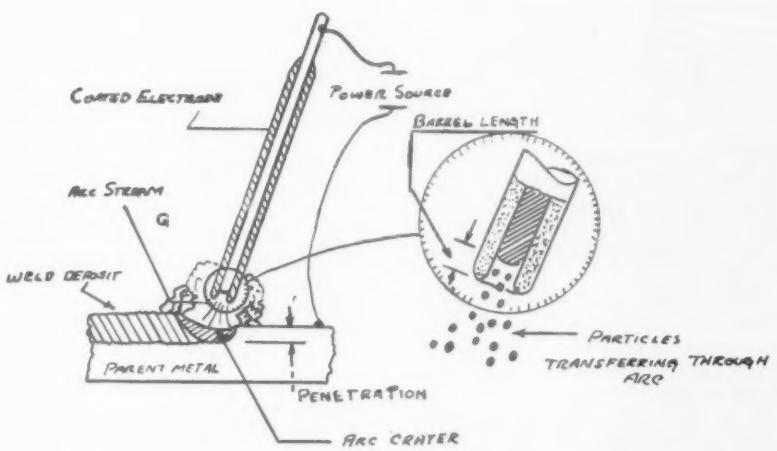

Fig. 1 Diagram of metallic arc welding, including illustrations of barrel length and penetration

Interest in underwater welding has lately been renewed in another field, that of the minimization of postwelding distortion. Several manufacturers of machine tools and machine components are having varied success in attempts to reduce distortion of machined parts by welding underwater. At the present this application is in the formative stages, and is used where parts are small and only the tip of the electrode need be submerged. It is readily seen that many of the difficulties inherent in fully underwater welding are eliminated in this field. In light of this, rapid machine welding of small parts underwater may soon prove feasible.

PURPOSE

As the technical aspects of underwater welding become known, industry may expect to more fully utilize the process in the fields of marine repair and distortion prevention. With this in mind, the research described in this paper was undertaken as an initial effort toward a better understanding of the theoretical side of underwater welding.

The following factors were investigated by making both above- and below-water test welds using various electrodes which were coated with different waterproofing agents:

1. Operating characteristics.
2. Penetration, barrel length and bead geometry.
3. Particle size distribution.

EXPERIMENTAL TECHNIQUE

The following $^1/_8$-in. diam electrodes were chosen because they exhibited varying penetrating power and are in common commercial use:

AWS classification	*Polarity used*
E-6010	DC-Reverse
E-6011	DC-Reverse
E-6012	DC-Straight
E-6013	DC-Straight

Each type of electrode was given waterproofing coatings of shellac, lacquer, water glass and paraffin. Each was investigated both above and below water. Each electrode was also tested in the untreated condition.

Particles transferred through the arc in above-water welding tests were collected in the manner set forth in a previous investigation.[2] Weld passes were made along the edge of a mild steel plate, so that the particles would pass by the edge of the plate and be collected in a pan of water. The collection of particles below-water was more difficult. Two steel plates, $^3/_8$-in. thick and 5 in. long were placed at angles of 45 deg to the horizontal in a pan of water, one plate slightly higher than the other. Their tip edges were approximately $^1/_4$ in. apart. A collecting pan was suspended in the space between the plates, and weld passes were made across the top of the higher plate with the electrode held perpendicular to the surface of the water. The depth of water over the top of the higher plate was 4 in. It was noted in trial runs that particles rolling off the higher plate had sufficient velocity to carry them over the top of the lower plate, so that they were not collected. Hence, only particles passing directly through the arc and past the edge of the plate were collected in the submerged pan.

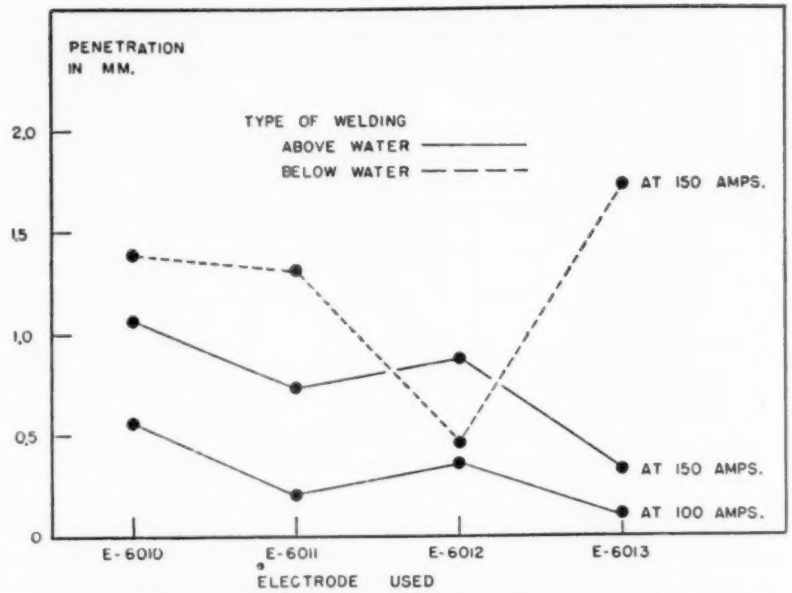

Fig. 2 Current-penetration characteristics for above-water and below-water welding without waterproof coating

All particles collected for each test were separately dried, screened, weighed, and plots of cumulative percent retained versus mesh size were made for each of the four electrodes at all of the five coating conditions.

Test beads were made for each electrode and waterproofing material combination below 4 in. of water. Each barrel length which, for the case of a positive barrel length, is the distance between the tip of the extruded coating and the tip of the filler wire, as shown in Fig. 1, was measured and recorded. Average values of barrel length were obtained from three runs at each condition. Each weld was sectioned, polished and etched so that the

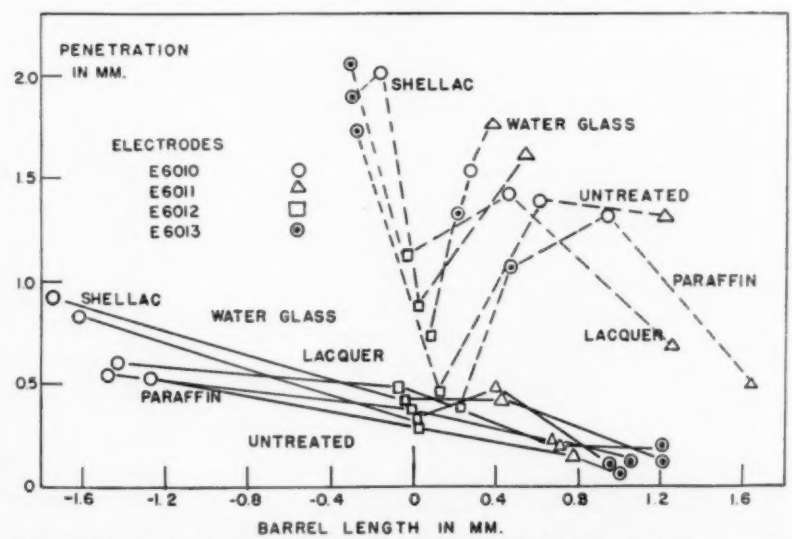

Fig. 3 Electrode characteristics as determined by the waterproofing agent. Broken lines signify below-water welding; solid lines show above-water welding

depth of penetration into the plate could be determined. Again, the average of three runs was determined. A Brinell microscope was used to measure the values of barrel length and penetration.

In all penetration tests weld beads were made on $^1/_4$-in. thick SAE 1020 steel plate using a $^3/_{16}$-in. arc length and an electrode travel rate of 15 ipm. A 50% increase in welding current was used to offset the anticipated underwater current leakage. Hence, welds were made at 100 amp above water and at 150 amp below water. In order to evaluate this estimate of current leakage, test welds were also made above water at 150 amp, using electrodes without waterproofing coatings. Depth of penetration and barrel length were determined at these conditions, holding the previously mentioned conditions constant.

Unsuccessful attempts were made to weld under water using alternating current. Regardless of the current magnitude used, it was impossible to maintain the arc due to the cyclic changes in current.

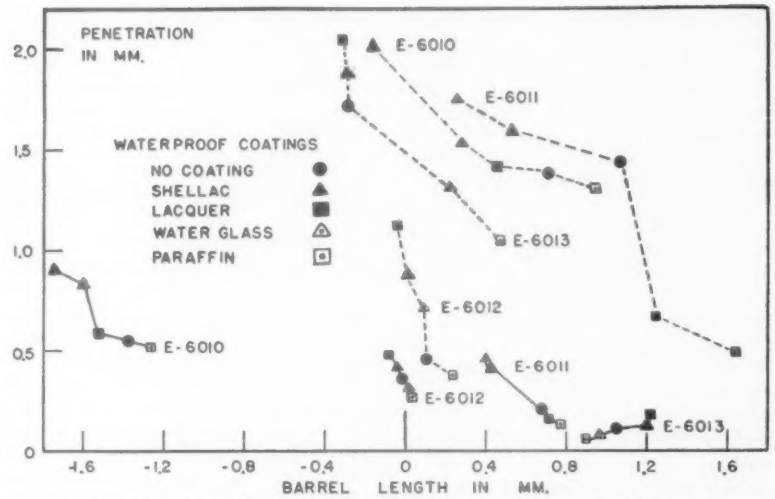

Fig. 4 Specific electrode characteristics. Broken lines signify below-water welding and solid lines indicate above-water welding

CURRENT-PENETRATION CHARACTERISTICS

Figure 2 indicates the relation which exists between penetration and welding current for both above- and below-water welding with untreated electrodes. The effect of increasing the above-water welding current from 100 to 150 amp caused, as anticipated, an increased depth of penetration for all of the electrodes. The increases for the E-6010, E-6011 and the E-6012 were approximately equal to $2^1/_2$ mm. The effect on the E-6013 was not as pronounced as on the others, increasing penetration only slightly more than one millimeter.

For all four electrodes the penetration obtained by welding at 150 amp under water was greater than the corresponding above-water penetration at 100 amp. The minimum increase, 30%, was with the E-6012 electrode. The other three showed increases of greater than 100%. This fact may be explained on the basis that the coating of the E-6012 rod offers less resistance to current flow when immersed, and thus has a correspondingly greater current leakage during underwater operation. From these two curves it is apparent that the estimate of underwater current leakage of one-third of the total current is too high for all but the E-6012 electrode. In light of these tests, it is felt that a current increase in the order of 10 to 20% would have been sufficient to compensate for leakage losses. The fact that the underwater current leakage was overestimated should be borne in mind during the discussion of the actual test results which appears in a later section.

A comparison of the curve for underwater welding at 150 amp with the above-water curve at 150 amp shows that the untreated E-6010, E-6011 and E-6013 electrodes give deeper penetration below than above water. Only the E-6012 gives deeper above-water penetration. The deeper underwater penetration of the three electrodes is indeed perplexing when one thinks solely in terms of equal electrical power input and postulated loss of current due to leakage during immersion.

ELECTRODE CHARACTERISTICS AS DETERMINED BY THE WATERPROOFING AGENTS

Figure 3 shows the effect of various waterproofing agents upon the operating characteristics of the four electrodes studied. Variation of barrel length with depth of weld penetration is plotted for each electrode and waterproofing agent combination for welds made above and below-water. On the basis of this graph a number of interesting correlations can be made.

It was noted that welding underwater gave deeper penetration than welding above-water for each test combination investigated. The import of this statement, however, should be tempered in light of the overestimated current leakage, as previously discussed.

The E-6011 electrode was found to have the longest barrel length in underwater welding for all waterproofing agents as well as the untreated condition. Oddly enough, this behavior is not characteristic of this electrode in above-water welding. To the contrary, with three combinations it had the shortest barrel length and with the other two it was the second shortest.

For every coating condition except waterproofing the rod with lacquer, the E-6012 electrode had the shallowest underwater penetration. Within the group of electrodes coated with lacquer, the E-6012 electrode was second in shallowness of penetration to the E-6011. A possible explanation for this phenomena is, as was postulated earlier, that the E-6012 is the least resistant to current leakage during underwater operation. From Fig. 3 it is noted that the underwater depth of penetration for the untreated E-6012 electrode is 0.46 mm. Comparing this value with the others for the treated condition it is seen that the shellac, water glass, and lacquer considerably increase the observed penetration. This may be attributed to a reduction in the magnitude of the current leakage. Surprisingly, the paraffin coating has the opposite effect, and causes a slight reduction in penetration. This effect of paraffin is not limited solely to the E-6012 electrode, but is also found in the other three rods. It would thus appear that the paraffin increases the magnitude of the current leakage. Similarly, the depth of penetration of the E-6011 is decreased by the lacquer coating and the E-6013 by the water glass.

A comparison of the depth of underwater penetration of the four untreated electrodes is revealing. The depths of penetration of E-6010, E-6011 and E-6013 fall within the range of 1.3–1.7 mm., whereas the E-6012 rod only penetrates to a depth of 0.46 mm. On the basis of surface coatings, this is probably due to the fact that the E-6012 rod is characterized by having the least resistance to current leakage through the coating while operating immersed. The E-6012 electrode is the only one to have a negative barrel length while operating underwater in the untreated condition.

Shellac as a waterproofing agent generally causes the formation of shorter barrel lengths than do the other waterproofing agents. Both the E-6010 and E-6013 have negative barrels and the E-6012 has a positive barrel length of only 0.02 mm.

The plot of penetration versus barrel

length for underwater welding using electrodes coated with waterglass gives an interesting correlation. Figure 3 shows a linear relation which has a positive slope. From this it is seen that the depth of penetration increases with increasing barrel length. This is, in itself, a surprising observation, since it is a sharp contradiction to the established rule for above-water welding with untreated electrodes that the depth of penetration and barrel length vary inversely.[3] It is also noted that the similar underwater curves for the other coating treatments investigated violate this generalization. It is apparent, therefore, that the inverse relationship does not hold for plots of the underwater characteristics of the electrodes which have received the same waterproofing coating.

The inverse relation discussed above will be seen in Fig. 4 to hold very well for the below-water plots of the same electrode with different waterproofing coatings. The sole exception to this is the case of the waterglass-coated E-6011 electrode. It should be mentioned here that the inverse relationship is borne out by the fact that the graphical electrode order is maintained independent of the waterproofing agent used. In order of having the longest barrel and least penetrating power the E-6013 ranks first. The ranking of the others from this is E-6011, E-6012 and E-6010. The coating condition generally had little effect on the characteristic depth of penetration and barrel length of the electrode in above-water welding.

ELECTRODE BEHAVIOR

Figure 4 shows the above and below-water variation in depth of penetration with barrel length as affected by the waterproofing agent for each electrode. It is seen that the below-water penetration of each electrode is greater than the above-water penetration for all of the waterproofing agents. This is as expected considering that the magnitude of the current leakage was overestimated. With both above-water and below-water welding the paraffin coating caused the shallowest penetration for all electrodes. It also gave the longest barrel lengths for all cases except above-water welding with the E-6013 rod. Barrel length was found to vary inversely with the depth of penetration for all cases except above-water welding with the E-6013 rod. Generally, the above-water welding was characterized by a narrower spread of barrel length and depth of penetration values for any given electrode than was obtained in below-water welding. The E-6010 electrode may be singled out as the only one which gave negative barrel length in above-water welding with all of the coating conditions investigated. The E-6011 rod was the only one which gave positive barrel lengths with all coating conditions for both above-water and below-water welding. For all coating treatments the E-6012 electrode gave exceptionally short positive and negative barrel lengths for both above- and below-water welding.

PARTICLE SIZE DISTRIBUTION

Underwater welding is characterized by a finer particle size distribution for all electrode-waterproofing coating combinations than is obtained in above-water welding.

The mechanism by which waterproofing agents determine the particle size distribution characteristics are not known. It is postulated that the vaporization of the coating during welding somehow changes the nature of the gaseous arc shield, thereby altering the mode of metal transfer through the arc.

ELECTRODE OPERATING CHARACTERISTICS

Any theoretical approach should be tempered by practical considerations. It is important to note the change in operating characteristics of each electrode when used underwater, and the further effect on these characteristics induced by the waterproofing materials.

No electrolytic corrosion was encountered in any tests using reverse polarity. This is not unusual, for the time of electrode immersion was never longer than ten seconds, and the electrode holder was not submerged. The E-6010 electrodes all spattered violently below-water. This was due to the original coating composition, and not polarity, since E-6011 electrodes, which also operated on reverse polarity, gave almost no spatter.

The E-6010 underwater welded beads were somewhat irregular. The electrode coating produced a gas which burned spasmodically at the water surface, obscuring the weld area. E-6011 electrodes were a considerable improvement, giving a low continuous bead which was comparable in appearance to welds made above-water. There was little difficulty maintaining an underwater arc with the E-6010 electrodes. E-6012 electrodes produced a high narrow bead of fair continuity. Neither the immersion nor the waterproofing coatings had a significant effect on the operating characteristics of the E-6012 rods. Variation in waterproofing coatings, however, did have an appreciable effect upon the welds made with the E-6013 electrodes. As a class they gave considerable spatter and a low wide bead with a slightly irregular surface. The E-6013 electrode ran much "hotter" under water than it normally does above water.

Electrodes which were not waterproofed were generally unsuitable for welding underwater. The extruded coatings chipped and pealed during underwater operation, and tended to scorch or burn unevenly as far as 3 in. up the rod. Arc maintenance was generally unaffected.

Shellac and waterglass exhibited almost identical characteristics. Both materials improved bead continuity and ease of arc maintenance for all electrodes. Shellac markedly reduced the tendency for undercutting, which is often a serious problem in underwater welding. Waterglass had little effect on the undercutting tendencies of the electrodes. The lacquer did not improve the general quality of the weldments made with the untreated electrodes, but did cause an unusual peak-shaped bead. Paraffin seemed to have little effect on electrode operation and weld surface appearance.

In all cases, welding in still water is difficult. The primary problem is the formation of colloidal dispersions of carbon and filler metal particles which immediately cloud the weld area, thus impairing observation. Welds must be made cautiously because the arc is easily broken.

SUMMARY

On the basis of this investigation the following six general conclusions may be drawn:

1. Underwater welding is characterized by a finer particle size distribution than is obtained in above-water welding for all electrode-waterproofing combinations.

2. The problem of current leakage through the coating is encountered in underwater welding. The magnitude of this leakage is in the probable range of 10–20%.

3. The specific electrode type and waterproofing agent used in underwater welding determines the characteristics attained.

4. Electrodes which have been waterproofed with the same agent show approximately the same barrel length and depth of penetration on above-water welding.

5. The variation in barrel length and depth of penetration with the type of waterproofing coating for a given electrode is greater for below-water welding than for above-water welding.

6. Waterglass causes a coarse particle size distribution and lacquer causes a fine particle size distribution when used as waterproofing agents for all electrodes in both above- and below-water welding.

Specifically, the E-6013 electrode with a waterproof coating of shellac was observed to be superior to other combinations as to maximum depth of penetration and avoidance of undercutting.

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Series Spot Welding of 0.036-In. Auto Body Steel

Optimum welding conditions for series or multiple-spot welding of low-carbon steel

by Ernest F. Nippes and Frederick H. Domina

Abstract

This investigation covers the use of series or multiple-spot welding equipment on 0.036-in. low-carbon auto body steel leading to the determination of the optimum welding conditions. Series spot welding differs from conventional spot welding in the respect that 2 to 16 welds, in even multiples, can be made at one time. The equipment is discussed and the procedure for the determination of optimum conditions is presented.

The investigation was conducted using two electrodes; and the effect of such variables as electrode geometry, electrode force, weld time, fusion-zone diameter, material thickness, surface preparation and spot spacing was determined. Strength-current characteristic curves are presented to illustrate the effect of these variables whenever possible.

The problem of short-current or shunt currents through the sheets being welded is discussed, and techniques and instrumentation to measure these currents were developed. In addition, the dynamic force-current characteristics of the equipment were studied. In this respect, other investigators should be warned that errors can easily be introduced when using strain gages mounted on welding electrodes.

INTRODUCTION

THIS program, approved and guided by the Series Spot Welding Subcommittee, was financially supported by the Welding Research Council of the Engineering Foundation. The object of this investigation was the study of the series spot-welding process leading to the determination of optimum conditions for as-received, degreased and pickled 0.036-in. auto-body stock. The dynamic force-current characteristics of the equipment were also studied along with instrumentation for measuring the shunting currents through the two sheets being welded and the backing bar holding the backing electrodes.

Ernest F. Nippes and **Frederick H. Domina** are with the Welding Laboratory, Department of Metallurgical Engineering, Rensselaer Polytechnic Institute, Troy, N. Y.

Presented at the AWS National Spring Meeting held in Buffalo, N. Y., May 4-7, 1954.

Table 1—Chemical Analysis and Mechanical Properties

Carbon, %	0.055
Manganese, %	0.33
Silicon, %	0.01
Phosphorus, %	0.01
Sulfur, %	0.035
Copper, %	0.09
Nickel, %	0.05
Chromium, %	0.01
Molybdenum, %	0.01
Tensile strength, psi	46,500
Yield strength (0.2%), psi	32,300
Elongation in 2 in., %	28.0

MATERIAL

Material from three different heats of a cold-rolled, low-carbon, open-hearth, commercial-quality, rimmed steel, generally used for automotive body components, was used in this investigation. Of these three heats of this type steel, two were furnished by the Fisher Body Division of the General Motors Corp. and one by the Ford Motor Co. Each of these steels was of different thickness, one heat being 0.032 in., another 0.036, and the third, 0.037 in. thick. In all cases, the surface of material in the as-received condition was covered with a protective film of oil and was essentially free of rust, dirt or other foreign substances. The majority of the work was done on the 0.036-in. material furnished by the Ford Motor Co. The chemical analysis and mechanical properties of this material are presented in Table 1.

EQUIPMENT

The equipment used in this investigation was furnished by the Fisher Body Division of the General Motors Corp., and was originally adapted to install on the platens of a press-type, toggle-operated resistance welder in the Welding Laboratory at Rensselaer. Inasmuch as this arrangement restricted the use of this spot welder, it was decided to build a separate frame and install the series spot welding equipment in it. Figure 1 shows the final arrangement of this equipment.

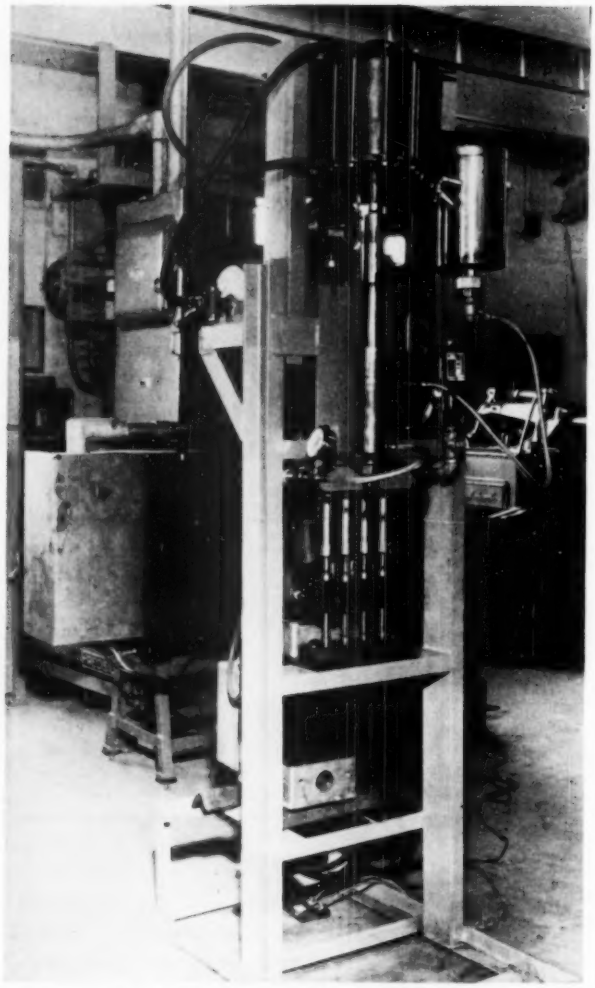

Fig. 1 Series spot welding equipment

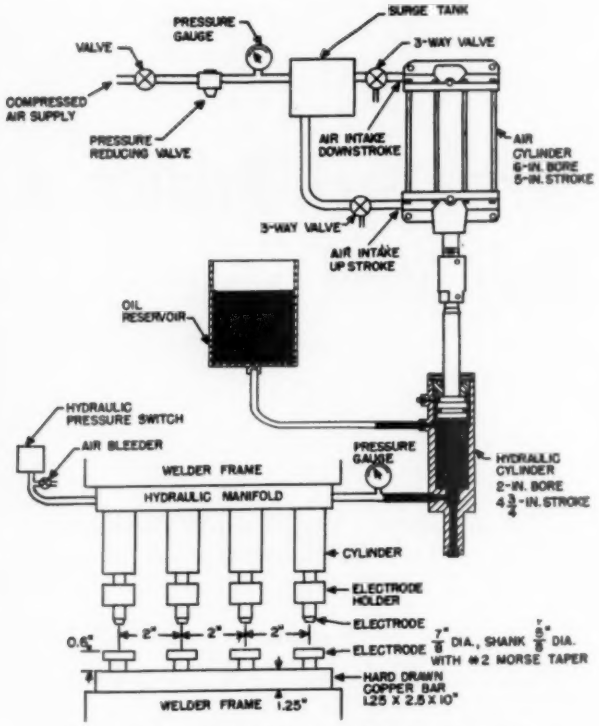

Fig. 2 Schematic of series welding equipment

In detail, the electrode force in this equipment (500 lb max) was supplied by an air-hydraulic system with manifold and equalizing guns, as shown in Fig. 2. The electrical system consisted of a 50-kva Hypersil transformer with tap switch, RWMA class 2 electrodes and a copper backing bar. The arrangement of the electrodes are shown in Fig. 2. The transformer had two secondary windings of equal impedance and was rated at 440 primary with the secondary voltage being regulated in approximately 8 equal steps from 4.58 to 6.88 v.

The power to the Hypersil transformer was derived from a 125 hp, 350-kva motor-generator set operating from a three-phase 4160-v, 60-cycle line. The output voltage of the single-phase, 60-cycle generator was adjustable from 250 to 550 v. Electronic controls were used for weld timing, and phase control was used for the adjustment of welding current. Welding current was measured by means of a General Electric I^2T meter[1] and welding time was recorded by use of a Brush self-inking oscillograph.

For measuring the dynamic force-current characteristics of the system, electrodes were prepared with four type A-8 SR-4 strain gages which were connected to a General Electric Current-Force Recorder. This equipment consists of an oscillator, an amplifier and a power unit with the traces being recorded on a magnetic oscillograph. Shunts were designed, built and calibrated for the primary and secondary welding circuits so they could be connected directly to the galvanometers in the oscillograph.

GENERAL PROCEDURE

Since in series spot welding at least two welds must be made simultaneously, standard-size RWMA shear samples could not be produced directly in this program. Therefore, for carrying out studies of the effect of welding current upon single spot shear strength for various welding conditions, tension-shear samples were used as shown in Fig. 3. These samples were sheared from the welded sheets, as shown in Fig. 3, to conform to RWMA Specifications.[2]

Prior to welding, material was treated in three different ways:

1. As-received.
2. Degreased with acetone.
3. Degreased with acetone and pickled for 15–20 sec in 50% HCl solution, water-rinsed, acetone-rinsed and air-dried.

The effect of these three methods of material preparation on the surface contact resistance is shown in Table 2.

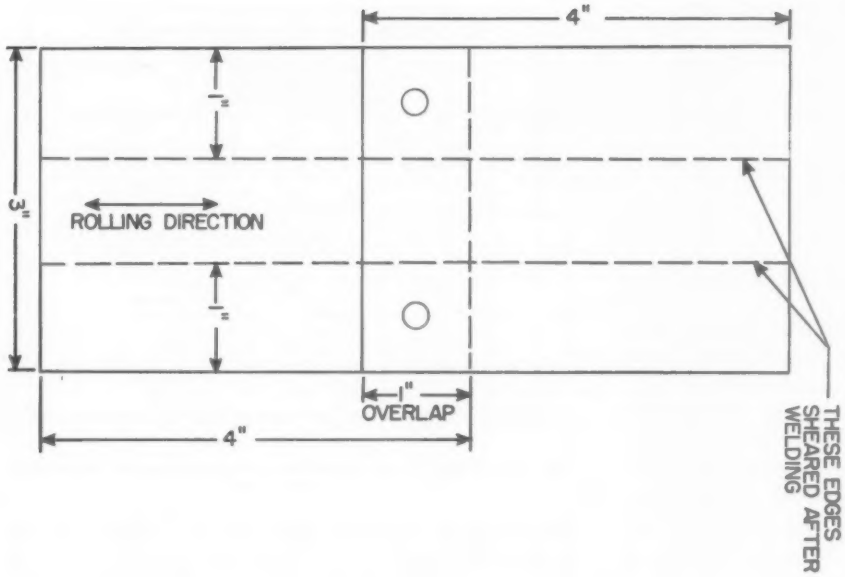

Fig. 3 Tension-shear test specimen

Table 2—Effect of Material Preparation on Surface Contact Resistance

$4^1/_2$-In. Radius Electrodes, 500 Lb Force, 0.036-In. Stock

	Contact resistance, microhms	
Condition	*Range*	*Average*
As-received	1400–3800	2000
Degreased	40–1500	400
Pickled	15–30	20

In addition to checking weld diameters by the "peel" test, samples were polished and etched, and fusion-zone diameters were measured with a microscope.

Welding Force and Electrode Geometry

The initial phase of this investigation involved the determination of the optimum welding force and electrode geometry that would produce porosity-free, sound welds in pickled stock. Inspection for soundness was accomplished by metallographic and radiographic techniques. From preliminary experiments and commercial practice, a welding time of 12 cycles was chosen for this portion of the program. With each electrode force and geometry investigated, the current was increased from low values which produced incipient welds up to the point where expulsion or surface flashing occurred. At a value of current just below the expulsion or flashing limit, the minimum force required to eliminate porosity was determined by radiographic or metallographic examination.

The following electrode geometries were investigated using $^5/_8$-in. diam RWMA Class 2 electrode material:

1. $^5/_{16}$-in. hemispherical radius.
2. $1^1/_2$-in. continuous radius.
3. 3-in. continuous radius.
4. $4^1/_2$-in. continuous radius.
5. $^1/_4$-in. restricted diameter with 3-in. radius.
6. $^1/_4$-in. restricted diameter with 6-in. radius.
7. $^3/_{16}$-in. restricted diameter with 6-in. radius.
8. $^7/_{32}$-in. restricted diameter with 6-in. radius.

With all these electrode geometries, 1-in. diam flat backing electrodes of the same RWMA class were used. Figure 4 shows the details of the various electrode geometries investigated.

Porosity-free welds could not be produced with the $^5/_{16}$-in. hemispherical radius electrodes in the freshly machined condition, regardless of the force used, since surface expulsion occurred with all practical values of welding current. Welds made using the $1^1/_2$-, 3- and $4^1/_2$-in. continuous radius electrodes could be produced without porosity; however, surface flashing and electrode sticking made these electrode geometries unsatisfactory. This difficulty was especially pronounced with the $1^1/_2$-in. radius electrodes. Surface flashing was also a problem with the geometry employing $^1/_4$-in. restricted diameter and 3-in. radius dome electrodes.

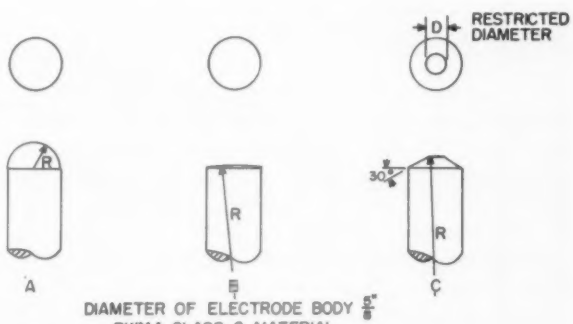
D
RESTRICTED DIAMETER
R
R
30°
R
A
B
C
DIAMETER OF ELECTRODE BODY 5/8"
RWMA CLASS 2 MATERIAL
A. 5/16" HEMISPHERICAL RADIUS
B. CONTINUOUS RADIUS TIPS (R = 1 1/2", 3" AND 4 1/2")
C. RESTRICTED DIAMETER WITH RADIUS DOME TIPS (D = 3/16", 7/32", 1/4" WITH R = 6" AND D = 1/4" WITH R = 3")

Fig. 4 Electrode geometries investigated

Table 3

Electrode geometry	Electrode force to eliminate porosity, lb
3/16 in. restricted diam, 6-in. radius dome	300
7/32 in. restricted diam, 6-in. radius dome	380
1/4 in. restricted diam, 6-in. radius dome	480
1/4 in. restricted diam, 3-in. radius dome	480
3 in. continuous radius	380
4 1/2 in. continuous radius	380

With the 3/16-, 7/32- and 1/4-in. restricted diameter electrodes that had a 6-in. radius dome, porosity-free welds could be produced. The 7/32-in. diam electrode was considered best because ample strengths and fusion-zone diameters could be obtained without the use of high electrode force. Table 3 summarizes the electrode force required to eliminate porosity for the electrode geometries which were found to give satisfactory welds.

Welding Time

With the optimum welding force established, the optimum welding time for pickled material was determined using the 7/32-in. restricted diameter electrode with 6-in. radius dome. The method used was the study of the effect of welding current upon shear strength for a variety of welding times. The welding currents investigated were those which ranged between the formation of an incipient, recrystallization-type weld to a weld size which would produce surface flashing or expulsion during the welding cycle.

Graphical representations of the effect of welding current upon shear strength for various welding times are shown in Fig. 5. From these results, 12 cycles were selected as the optimum, although 10–14 cycles may be considered a satisfactory range. As may be seen from Fig. 5, an increase or decrease in welding time outside this range resulted in diminished values of the shear strength. At the optimum of 12 cycles, a slight variation in time due to a lack of proper control will result in very little change in strength.

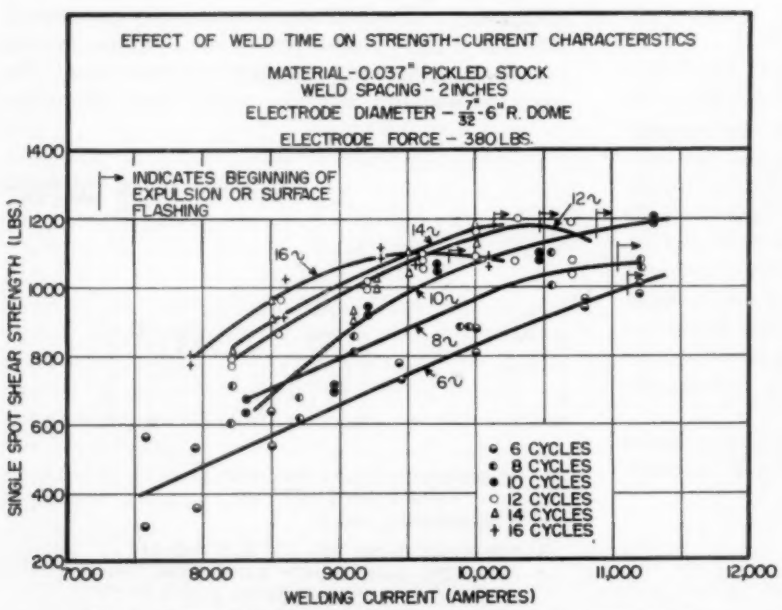

Fig. 5 Effect of Weld time on strength-current characteristics

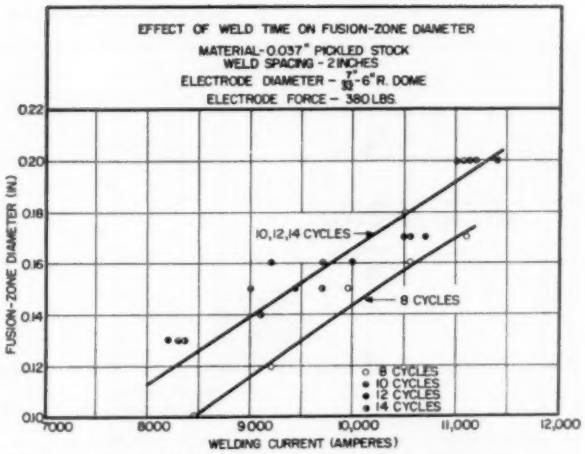

Fig. 6 Effect of Weld time on fusion-zone diameter

Fusion-zone diameter versus welding current curves are presented in Fig. 6 to show the effect of time upon the extent of fusion during welding. Within the accuracy of measurement, little or no difference was noted among welding times of 10, 12 and 14 cycles. These results are in agreement with those used to select the optimum range of welding time by the shear strength vs. welding current method.

Optimum Conditions—Strength-Current Characteristics

The optimum current range is best selected by determining a strength - current characteristic curve. As this had been accomplished in determining the optimum welding time, it was only necessary to recheck the curve using optimum conditions. The range of current was selected from these new curves. Figure 7 shows a plot of strength-current curves for the 1 1/2-, 3- and 4 1/2- in. continuous radius electrodes. As may be seen from this graph, welds made with 3- and 4 1/2-in. continuous radius electrodes require approximately 13,000 to 14,000 amp to attain an 1100-lb weld strength. With the 1 1/2-in. radius tip, severe surface expulsion occurs before a range of current is found that produces a reasonable value of weld strength. Also, in Fig. 7, a plot of a strength-current curve made with a 7/32-in. restricted

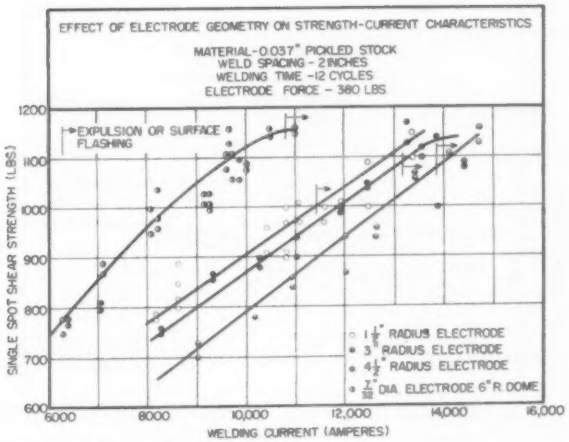
EFFECT OF ELECTRODE GEOMETRY ON STRENGTH-CURRENT CHARACTERISTICS
MATERIAL - 0.037" PICKLED STOCK
WELD SPACING - 2 INCHES
WELDING TIME - 12 CYCLES
ELECTRODE FORCE - 380 LBS.
EXPULSION OR SURFACE FLASHING
1½" RADIUS ELECTRODE
3" RADIUS ELECTRODE
4½" RADIUS ELECTRODE
7/32" DIA. ELECTRODE 6" R. DOME
SINGLE SPOT SHEAR STRENGTH (LBS.)
WELDING CURRENT (AMPERES)

Fig. 7 Effect of electrode geometry on strength-current characteristics

diameter, 6-in. radius domed electrode is shown. It may be noted that with these conditions, an 1100-lb weld strength is obtained at approximately 10,000 amp. Generally speaking, welds made in this investigation which exhibited a strength greater than 900 lb displayed a ductile-tear or plug-type failure. On the other hand, shear-type failures were noted consistently for welds with strengths less than 800 lb. In the range of weld strength from 800 to 900 lb, both types of weld failure were observed.

Effect of Material Preparation. Strength-current characteristic curves were made for the three methods of preparation mentioned under General Procedure; that is, with as-received, with degreased and pickled material. Figure 8 shows a plot of strength-current characteristic curves for the material in these three conditions. The shear strength curves for these three methods of preparation show the usual gradual increase in strength with welding current until a maximum shear strength value is obtained. Further increase in welding current causes expulsion and a slight decrease in shear strength due to the porosity that is obtained during expulsion in the welding operation. The effect of electrode deterioration is illustrated in Figs. 9 and

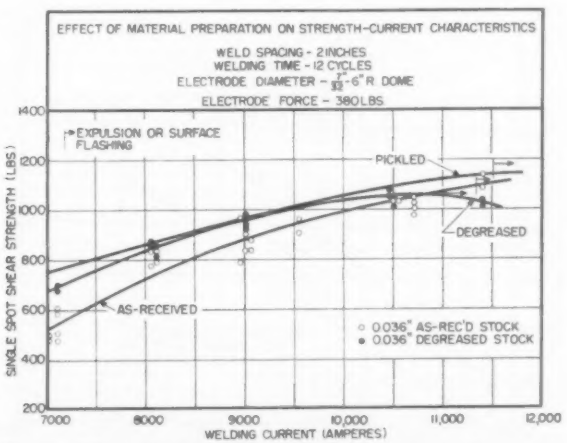

Fig. 8 Effect of material preparation on strength-current characteristics

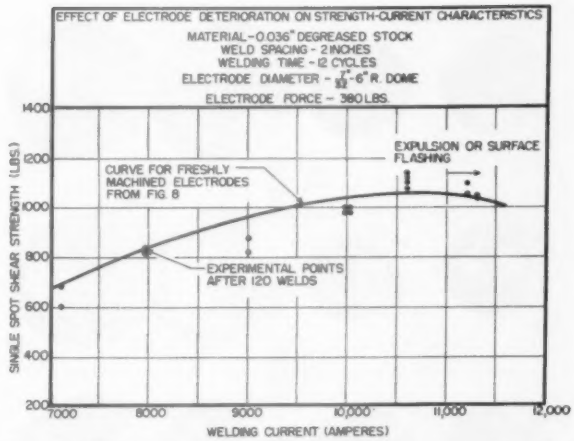
EFFECT OF ELECTRODE DETERIORATION ON STRENGTH-CURRENT CHARACTERISTICS
MATERIAL - 0.036" DEGREASED STOCK
WELD SPACING - 2 INCHES
WELDING TIME - 12 CYCLES
ELECTRODE DIAMETER - 7/32"-6" R. DOME
ELECTRODE FORCE - 380 LBS.
CURVE FOR FRESHLY MACHINED ELECTRODES FROM FIG. 8
EXPULSION OR SURFACE FLASHING
EXPERIMENTAL POINTS AFTER 120 WELDS
SINGLE SPOT SHEAR STRENGTH (LBS.)
WELDING CURRENT (AMPERES)

Fig. 9 Effect of electrode deterioration on strength-current characteristics, degreased stock

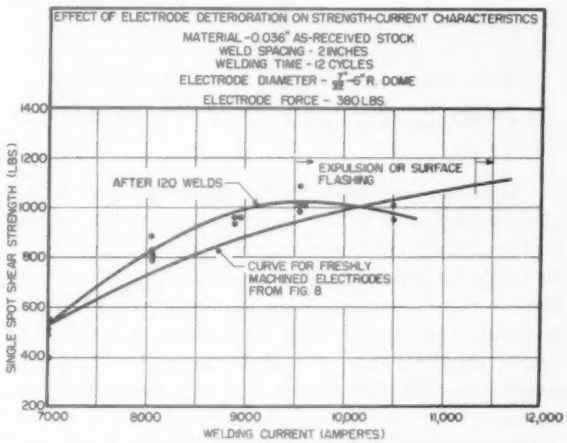
EFFECT OF ELECTRODE DETERIORATION ON STRENGTH-CURRENT CHARACTERISTICS
MATERIAL - 0.036" AS-RECEIVED STOCK
WELD SPACING - 2 INCHES
WELDING TIME - 12 CYCLES
ELECTRODE DIAMETER - 7/32"-6" R. DOME
ELECTRODE FORCE - 380 LBS.
AFTER 120 WELDS
EXPULSION OR SURFACE FLASHING
CURVE FOR FRESHLY MACHINED ELECTRODES FROM FIG. 8
SINGLE SPOT SHEAR STRENGTH (LBS.)
WELDING CURRENT (AMPERES)

Fig. 10 Effect of electrode deterioration on strength-current characteristics, as-received stock

10 which are plots showing the change in the strength-current curve during welding of degreased and of as-received stock, respectively. As illustrated in Fig. 9, there is little or no change in the strength-current characteristics or in the expulsion or surface flashing point for degreased material. This is also the case for the pickled material; however, as shown in Fig. 10, when welding as-received material, the expulsion point was lowered from 11,500 to 9500 amp after only 120 welds. In addition, these welds made at 9500 amp showed porosity when X-rayed. Figure 11 shows the deterioration that takes place on electrodes particularly when used for welding as-received material. This deterioration results from the foreign matter, such as oil and dirt particles, that is present on the as-received material. This photograph was taken after 120 welds were made with each set of electrodes. In this photograph Set A was used for welding as-received material, Set B for welding degreased material and Set C for pickled material.

Effect of Material Thickness. Three heats of steel which were of different thickness, as was mentioned un-

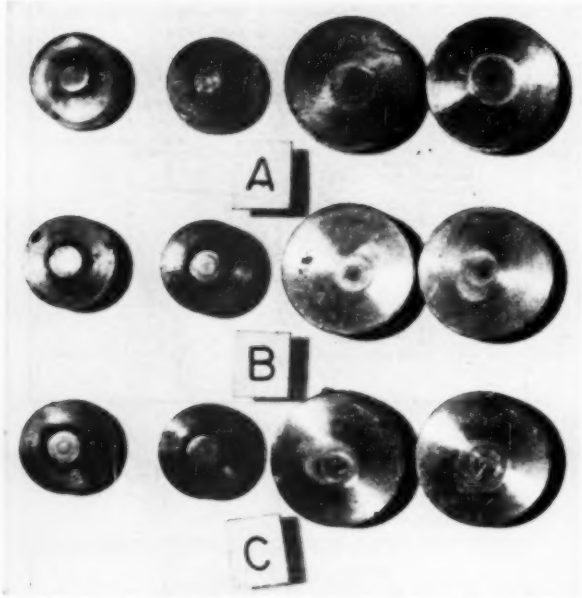

Fig. 11 Deterioration of electrodes after 120 welds

A. Welding as-received material. B. Welding degreased material. C. Welding pickled material.

der Material, were used in this investigation. Figure 12 shows a plot of tensile shear strength versus current for the average thicknesses of 0.032, 0.036 and 0.037 in. As might be expected, for a given welding current the highest shear strengths were found with the 0.037-in. material, the lowest with the 0.032-in. stock. Of course, chemical analysis and the amount of cold work would also affect the position of the strength-current curves.

Effect of Weld Spacing. Figure 13 summarizes the effect of weld spacing on the strength-current characteristics of 0.036-in. pickled material. Included in this figure are data for 2-, 4- and 6-in. weld spacings, as well as data for separate sheets. The arrangement of material using separate sheets, as compared with conventional series spot welding, is illustrated in Fig. 16, *1*

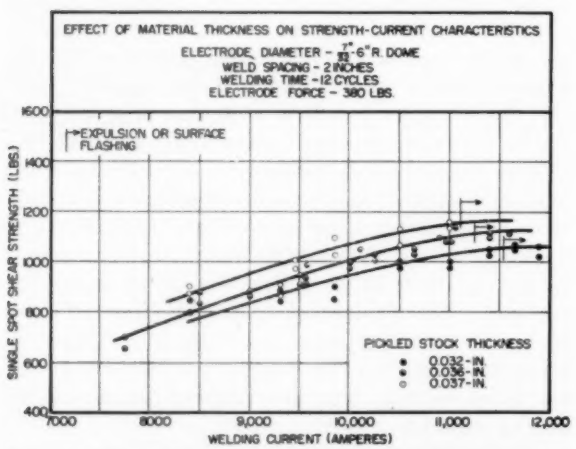

Fig. 12 Effect of material thickness on strength-current characteristics

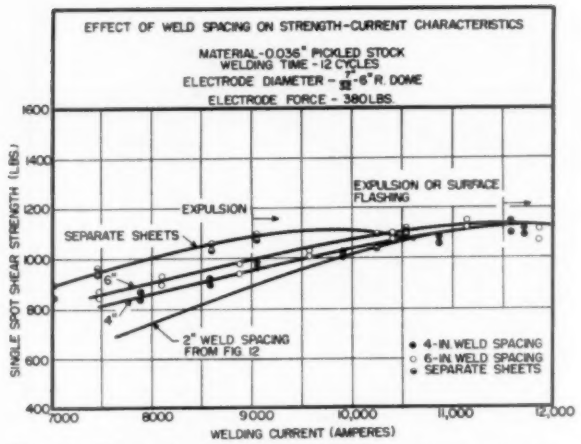

Fig. 13 Effect of weld spacing on strength-current characteristics

and *2*. The data summarized in Fig. 13 indicated that at lower currents, the strength values for the 6-in. weld spacing were highest, and those for the 2-in. spacing were lowest. However, in the optimum current range from 10,000 to 11,500 amp, the effect of weld spacing became relatively unimportant. Furthermore, the current value for the beginning of surface flashing or expulsion was identical (11,500 amp) for the three spacings investigated. In the case of welding with separate sheets, the current value for the beginning of expulsion was considerably lower (9000 amp), and surface flashing was not encountered.

Peel Test. In Fig. 14 are presented data of weld diameter versus current that were obtained using the "peel" test. These results were obtained on pickled 0.036-in. material using the following procedure. A series of successive spots were made approximately $1^1/_2$ in. apart on two 4-x 8-in. sheets. A 1-in. chisel was driven between two adjoining welds deep enough to rupture them and the average diameter was then measured. Also shown in Fig. 14 is a plot of fusion-zone diameter as determined by microscopic methods. In general the diameter is measured by the peel test

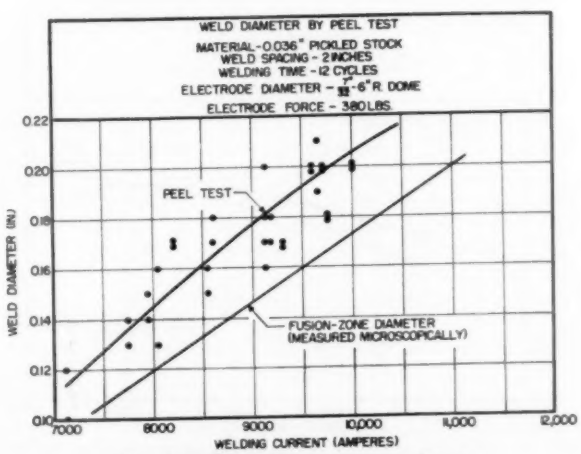
WELD DIAMETER BY PEEL TEST
MATERIAL - 0.036" PICKLED STOCK
WELD SPACING - 2 INCHES
WELDING TIME - 12 CYCLES
ELECTRODE DIAMETER - 7/32"-6" R. DOME
ELECTRODE FORCE - 380 LBS.
PEEL TEST
FUSION-ZONE DIAMETER (MEASURED MICROSCOPICALLY)
WELD DIAMETER (IN.)
WELDING CURRENT (AMPERES)

Fig. 14 Weld diameter by peel test

Table 4—Optimum Conditions* for Series Spot Welding 0.036-In. Auto-Body Stock

Preparation of material	*Electrode geometry*	*Electrode force, lb*	*Weld time, cycles*	*Welding current, amp*	*Weld diam, in.*	*Single-spot tensile shear strength, lb*
Pickled or degreased	7/32 in. restricted diam with 6-in. radius dome	380 range: 360–400	12 range: 10–14	10,700 range: 10,000–11,500	0.18 range: 0.17–0.20	1050 range: 1000–1100
As-received	7/32 in. restricted diam with 6-in. radius dome	380 range: 360–400	12 range: 10–14	9500 range: 9000–10,000	0.17 range: 0.16–0.20	1000 range: 950–1050

* The above conditions are applicable for weld spacings from 2 to 6 in.

was approximately 0.03 in. larger than that of the fusion zone.

Optimum Conditions. The optimum conditions for as-received, degreased and pickled materials, as determined in this investigation, are listed in Table 4. These data show equivalent welding conditions for the material that had been either degreased or pickled. However, the current requirements for satisfactory welds in the as-received material were approximately 1000 amp less than that required for the degreased or pickled material. Furthermore, materials in the as-received condition will cause fairly rapid electrode deterioration, as was noted previously in Fig.. 11. Additional investigative effort is planned on the welding of as-received material.

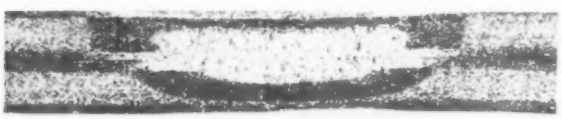

Fig. 15 Photomacrograph of typical series spot weld. Etchant, Nital. Magnification. ×7

Figure 15 is a photomacrograph at 10 × of a weld characteristic of those produced by series spot welding. This weld was produced in pickled stock using the optimum conditions listed in Table 4, with a current of 11,500 amp, the upper limit of the recommended current range. With greater current values, a displacement of the fusion zone and the heat-affected zone toward the direction of the other weld was usually noticed.

Short-Circuit or Shunt Current

In series spot welding there are three paths through which the welding current may flow from one electrode to the other. These paths are: (1) through the backing electrodes and backing bar, which is the most likely as these are made of copper; (2) through the top sheet being welded; and (3) through the bottom sheet. The current through these latter two paths may be considered as a short-circuit or shunt current.

An approximation was used to ascertain the relative value of this shunt current by making welds with four different conditions, as follows: (1) continuous sheets top and bottom; (2) separate sheets top and bottom; (3) separate sheets on top and continuous sheet on the bottom; and (4) continuous sheet on top and separate

Table 5—Short Circuit or Shunt Current Study

7/32 In. Restricted Diameter Electrodes with 6-In. Radius Dome. 0.037-In. Pickled Stock, 380-Lb Electrode Force

Placement of sheet	*Welding current required to produce 1100-lb weld, amp*
2-in. weld spacing	
Continuous sheets top and bottom	10,500
Separate sheets top and bottom	7,900
Separate sheets on top, continuous sheet on bottom	8,700
Continuous sheet on top, separate sheets on bottom	10,300
4-in. weld spacing	
Continuous sheets top and bottom	10,400
Separate sheets top and bottom	7,900
Separate sheets on top, continuous sheet on bottom	8,600

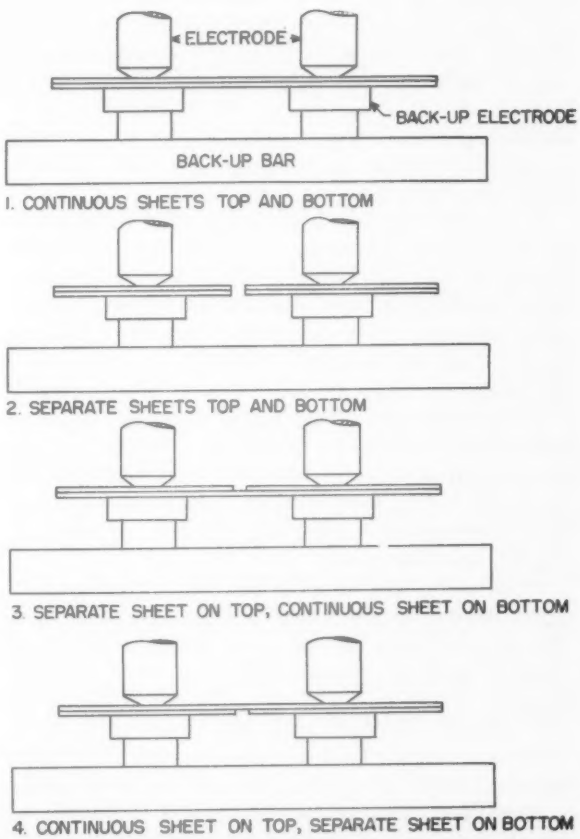
ELECTRODE
BACK-UP ELECTRODE
BACK-UP BAR
1. CONTINUOUS SHEETS TOP AND BOTTOM
2. SEPARATE SHEETS TOP AND BOTTOM
3. SEPARATE SHEET ON TOP, CONTINUOUS SHEET ON BOTTOM
4. CONTINUOUS SHEET ON TOP, SEPARATE SHEET ON BOTTOM

Fig. 16 Arrangement for measuring relative effect of short-circuit current

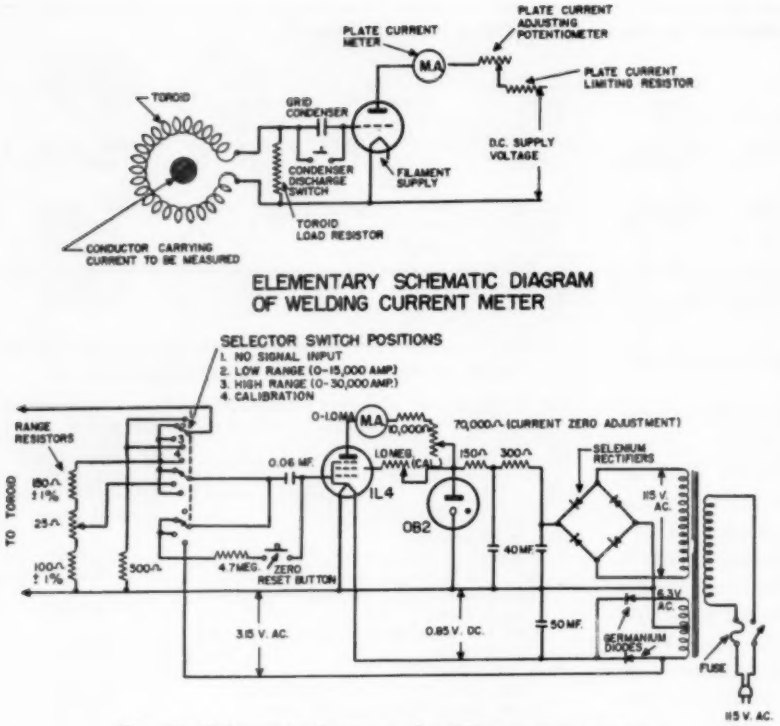

Fig. 17 Schematic diagram of welding current meter

sheets on the bottom. These arrangements are shown schematically in Fig. 16. Strength-current characteristic curves were determined for each condition and the welding current necessary to make the same strength weld in each case was tabulated in Table 5. As an example of the shunt current for 2- and 4-in. weld spacings, approximately 25% less current was required to make a weld of the same strength with separate sheets than with the continuous sheets.

It was felt that this approximate determination of the short-circuit current gave an indication pronounced enough to warrant further investigation. Instrumentation to determine such currents is not readily available; however, the Fisher Body Division of General Motors Corp. has developed a toroidal pick-up vacuum-tube ammeter which is used for measuring secondary welding current.[3-7] This meter appeared to have considerable promise for providing a simple, convenient method of measuring the actual welding current in the sheets. As a result of these considerations, one of these instruments, a schematic of which is shown in Fig. 17, was constructed.

When using this toroid it is necessary to use full-phase current as the toroid is a differentiating unit. This means that if the conductor passing through the toroid is carrying a current with a sine wave form, the induced voltage in the toroid will cause a current to flow through the load across the toroid which has a cosine wave from 90 deg out of phase with the original current. Other wave forms, such as that produced by a phase-shift network, would give a differentiated toroid output current that will not resemble the original current.

To simplify the measurement of the short duration output voltage of the toroid, a peak-reading, a-c vacuum tube voltmeter circuit is employed. In this vacuum tube voltmeter design, the toroid voltage is used to control the grid bias of a vacuum tube, and thereby the plate current of the tube. A condenser in the grid circuit, charged by grid rectification of the vacuum tube to the peak value of voltage developed by the toroid, determines the negative grid bias of the tube. To obtain straight line calibrations, the circuit constants are selected so that the plate current of the vacuum tube is proportional to the grid bias. This steady-state plate current is measured by a milliammeter. By this method, the short duration output voltage of the toroid is changed to a steady-state meter indication which is not affected by the duration of the toroid voltage. The circuit is designed and adjusted so that a maximum plate current of 1.0 ma will flow when the toroid output voltage is zero. Since any voltage produced by the toroid will increase the negative grid bias of the tube and decrease the amount of plate current, the meter reads backward. Hence, with no welding current a maximum meter reading corresponding to maximum plate current results; while with the maximum welding current that can be measured a zero plate current and a zero meter reading results.

The instrument at Rensselaer was constructed in conjunction with a commercially wound toroid and was calibrated with a General Electric I^2T meter to measure current through the electrodes during this investigation. Although shunt currents were not measured in the sheets during the present investigation, a procedure has been developed by which this can be accomplished. Figure 18 illustrates the intended use of the instrument. This procedure can be used since magnetic flux produced by conductors outside the toroid loop, even though

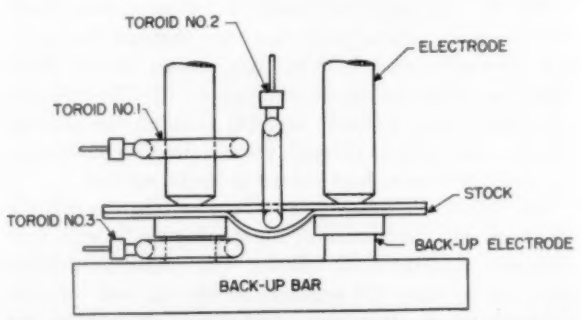

Fig. 18 Schematic of toroid method of measuring short-circuit current

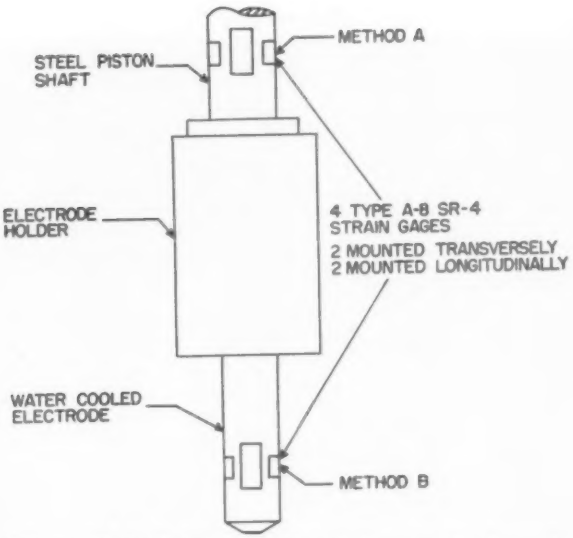

Fig. 19 Methods for mounting strain gages for dynamic measurement of electrode force

they may be immediately adjacent to the toroid, do not produce any toroid voltage. By using a number of toroids which is one less than the number of unknown currents it is possible to establish the current flow in all paths. Toroid No. 1 as shown in Fig. 18 will give the total secondary current and the sum of the other current paths will equal this value. These values shall be reported in a future investigation.

Dynamic Force-Current Measurement

During welding, electrode force was measured dynamically by the use of electric strain gages, as mentioned under Equipment. In the original arrangement the strain gages were mounted approximately $^3/_4$ in. from the tip of the water-cooled electrode, as illustrated in Fig. 19, Method B. The dynamic force record resulting from this technique is shown in the upper portion of Fig. 20. In this case, the electrode force dropped during welding, rose rapidly after welding to a value double the normal value, and slowly returned to the original static value. After much experimentation, this behavior was ascribed to the flow of heat from the electrode tip during and after welding. Normally a strain-gage bridge is self temperature compensating; however, this is only true when the gages are at the same temperature.

In the case at hand, the flow of heat established along the water-cooled electrode a temperature gradient which varied with time. Thus, the lower end of the longitudinally mounted strain gages experienced a different thermal cycle than the lower edge of the transversely mounted gages. As a result, the change in resistance of the longitudinal gages with time was different from that of the transverse gages. The resulting unbalance of the strain-gage bridge produced spurious force readings.

To overcome this difficulty, strain gages were mounted

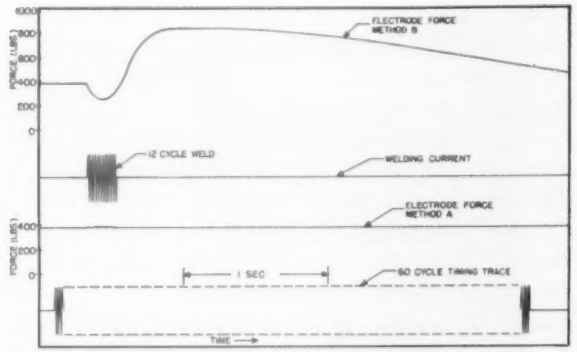

Fig. 20 Sketch of oscillograph record of dynamic measurement of electrode force

on the steel piston shaft of the electrode assembly as illustrated in Fig. 19, Method A. The dynamic force record for this improved technique is shown in Fig. 20 in the lower portion of the oscillograph. This record, showing little or no change in electrode force during the welding operation, demonstrates the excellent response of the air-hydraulic electrode force system used in this investigation.

SUMMARY AND CONCLUSIONS

The following summarizes the results of this investigation of the series spot welding of 0.036-in. low-carbon steel auto-body stock.

1. The effect of such variables as electrode geometry, electrode force, weld time, fusion-zone diameter, material thickness, surface preparation and spot spacing was determined. Strength-current characteristic curves have been presented to illustrate the effect of these variables whenever possible.

2. Satisfactory conditions were established for welding both degreased and pickled stock for welding spacings from 2 to 6 in.

3. For 2-, 4- and 6-in. weld spacings, the three spot spacings investigated, the optimum current range was essentially the same.

4. Tentative conditions were also established for welding as-received stock; however, in this case electrode deterioration was comparatively rapid. Additional investigative effort is planned on the welding of as-received material.

5. For 2- and 4-in. weld spacings, the value of the short-circuit or shunt currents through the sheets being welded may be as high as 25% of the total welding current. Methods and instrumentation for measurement of these shunt currents were developed.

6. Dynamic force-current characteristics of the equipment were studied. In this respect, other investigators should be warned that errors can easily be introduced when using strain gages mounted on welding electrodes.

ACKNOWLEDGMENTS

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Yield Strength of Weld Metals at Elevated Temperature

Abstracted by Dr. G. E. Claussen

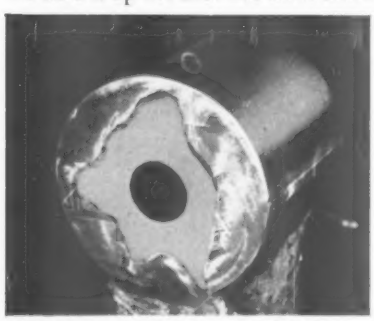
THE Swedish welding magazine *Svetsaren* in its issue No. 4 for 1953 lists the following yield strengths determined on all-weld-metal specimens by T. Norén and B. Ramshage. The first ten weld metals were deposited by covered corrosion and heat-resisting steel electrodes. The last weld metal was deposited by a high-tensile low-hydrogen electrode. The yield strength at 0.2% set was determined in three conditions: as-welded, stress relieved at 600–650° C and normalized. The electrode was used on reverse polarity and deposited 0.31 and 0.34 lb/1000 amp/min, respectively, of core rod and weld metal.

Composition of weld metal, %					*Yield strength, 1000 psi at:*					
C	*Cr*	*Ni*	*Mo*	*Cb*	*20° C*	*100° C*	*200° C*	*300° C*	*350° C*	*400° C*
0.07	18	9	...	...	54	48	44	43	41	41
0.07	18	9	...	1	66	61	57	55	54	53
0.07	19	8.5	1.5	...	64	57	51	51	51	48
0.07	18	9	1.5	...	58	50	47	46	44	41
0.20	25	..	...	...	54	50	47	50	51	46
0.17	24	5	...	...	74	66	60	56	56	54
0.07	19	8.5	2.5	...	68	63	57	53	51	51
0.07	18	9	2.5	...	73	66	60	56	54	53
0.13	26	21	...	...	48	44	40	37	36	36
0.20	24	5	1.5	...	76	68	63	57	56	53
C	*Si*	*Mn*	*Mo*							
0.10	0.50	1.50	0.40–0.50	As-welded	83	80	76	74	70	67
0.10	0.50	1.50	0.40–0.50	Stress relieved	77	74	71	68	66	64
0.10	0.50	1.50	0.40–0.50	Normalized	54	52	50	48	47	45

THREE DIFFERENT BREAKS in two years. Each would have normally condemned this costly equipment to the scrap heap.

This 5-ton cast-iron column of a drop-forge hammer was braze-welded with Anaconda Tobin Bronze Rod

"We've done many jobs of this type," says Wilson E. Campbell, Sr., President of Industrial Welding & Brazing, Inc., Lansing, Michigan, "but repairing this 10,000-lb. column casting for a drop hammer was as tough as any. Yet we fixed it up not once but three times



REBUILT INSIDE AND OUT with Tobin Bronze. Large punch press connection was bored for the bearing and ground off outside.

—in three *different* places—each time as good as new.

"Last year," Mr. Campbell continues, "we repaired over a thousand different parts for *one* large auto maker. We did most of this work with Tobin Bronze—our favorite welding rod for over 30 years."

Why does Industrial Welding like braze-welding for repair work? It's economical and dependable, and needs less preheating. High stresses don't build up, and there is less danger of cracking.

Why Tobin Bronze* Welding Rod? Mr. Campbell reports: "Tobin Bronze Welding Rod flows freely—'tins' fast—bonds strong and sound. It's good for a wide variety of repair welds—engine blocks, cast-iron pipe, machinery parts and other equipment."

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Composite photo of one torch and jet mixer with three different welding tips: 13, 7 and 1.
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